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GEOMORPHOLOGY OF THE RUBY-EAST HUMBOLDT RANGE, NEVADA

BY ROBERT P. SHARP

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ABSTRACT

A middle or late Pliocene open-valley stage in the Ruby-East Humboldt Range is recognized and described. The anomalous position of the drainage divide in places east of the range crest is explained in terms of the geomorphic evolution of the range. Pediments and terraces on the range flanks and in the adjoining basins are described, and those on the west side formed under a régime of through-flowing drainage are compared with those on the east side formed on the borders of hydrographically closed basins.

Seven surfaces, the two highest being pediments and the others partial pediments and terraces, are recognized on the west flank of the range. The dissection of these surfaces is shown to be related to successive rejuvenations of the Humboldt River drainage. The exposure and dissection of surfaces on the east flank of the range are attributed chiefly to relative uplift of the range by faulting. These pediments and terraces have been formed between the middle Pleistocene and Recent.

The origin of pediments under contrasting conditions is considered, and the conclusion is reached that different geologic, climatic, and topographic conditions impose a difference in the efficacy of processes of pedimentation. In this region lateral planation is dominant in areas of permanent streams and soft rocks; and rill wash, rain wash, and weathering are dominant in areas of hard rocks, ephemeral streams, and low mountain masses.

Lateral erosion by streams accounts for approximately 40 per cent of the retreat of the mountain front, and approximately 60 per cent is due to weathering and various types of wash.

INTRODUCTION

INTRODUCTORY STATEMENT

This paper is devoted chiefly to consideration of pediments and terraces flanking the Ruby-East Humboldt Range and in the adjoining basins. The geomorphic forms on the west side of the range, developed under a régime of exterior drainage, are compared with those on the east side, developed in an area of interior drainage. The geomorphological evolution of a progressively uplifted and tilted fault block, such as the Ruby-East Humboldt Range, would be of great interest, but, unfortunately, extended dissection of the mountain block makes this area unsuited for such studies. The glaciation of the range and some of the forms produced by block faulting have already been described (Sharp, 1938, 1939b) and will not be discussed further.

A total of 5 months during the summers of 1936 and 1937 were devoted to field work in the Ruby-East Humboldt region with particular emphasis on its Cenozoic history.

Sincere appreciation and acknowledgment are extended to Professors Kirk Bryan and Marland P. Billings, of Harvard University, for their interest, aid, and suggestions in the field and laboratory. Professor H. A. Meyerhoff, of Smith College, thoroughly criticised the manuscript and

FIGURE 1.—*Index map*
Ruby-East Humboldt Range shown in solid black.

offered several excellent suggestions. Edward A. Schmitz aided in the preparation of illustrations. Profit has been derived from the interest and suggestions of Dr. Leland Horberg and Jean Todd Sharp.

LOCATION AND PHYSICAL FEATURES

The Ruby-East Humboldt Range is located in Elko County, northeastern Nevada, 200 miles west of Salt Lake City, Utah (Fig. 1). It lies well within the borders of the Great Basin section of the Basin-Range province.

This range is a narrow, asymmetric fault block extending nearly 100 miles S. 20° W. from its northern end near Wells. Its high eastern face drops off steeply to the hydrographically closed, detritus-filled basins on

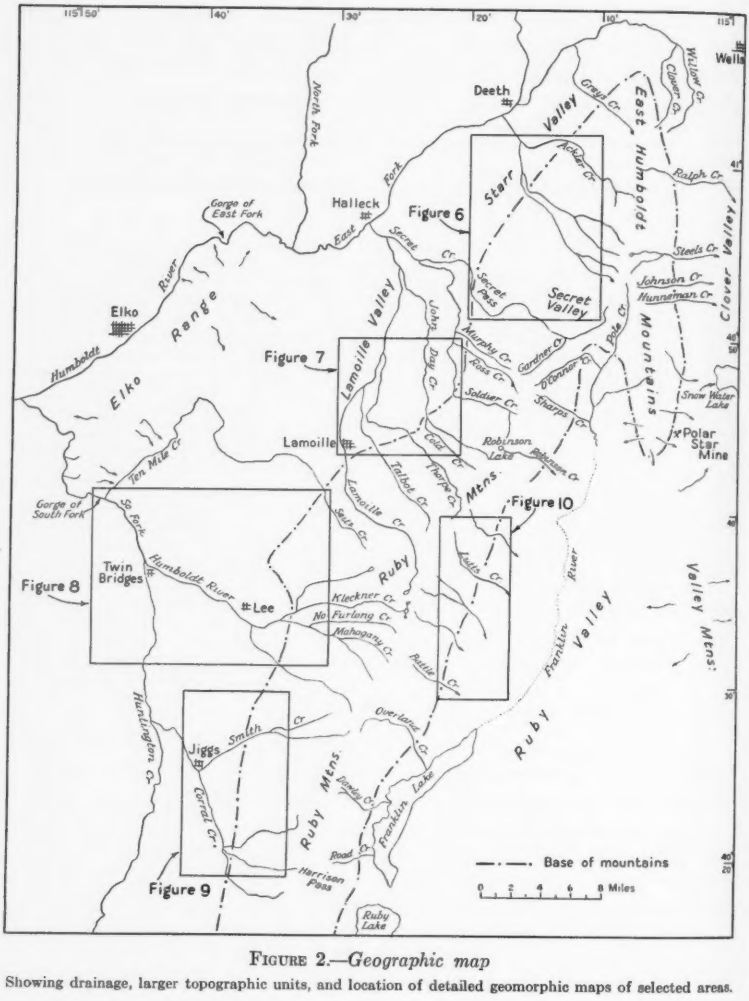

FIGURE 2.—*Geographic map*

Showing drainage, larger topographic units, and location of detailed geomorphic maps of selected areas.

the east. The western slope is longer and less steep, though rough and mountainous. To the west, an elongate basin approximately 15 miles wide separates the Ruby-East Humboldt Range from the low, subdued Elko Range (Fig. 2). This basin is drained and dissected by tributaries of the Humboldt River.

The crest of the range has an average altitude of 10,000 feet, the higher peaks are between 11,300 and 11,400 feet, and the adjoining basins lie between 5000 and 6000 feet.

Figure 2 covers an area of approximately 2700 square miles which includes all the localities and features to be described. Thirty per cent, or roughly 800 square miles, of this area consists of mountains and hills; the remaining 70 per cent, or roughly 1900 square miles, consists of plains, low hills, and badlands—the so-called basin country.

The basins adjoining the range have an annual rainfall of 8 to 10 inches, the flanks receive 13 to 15 inches, and the higher parts receive 15 to 18 inches annually. These figures are higher than the average for most of Nevada (Fassig, 1932). Most of the precipitation occurs from November to May, although summer thunder showers are common and occasionally are of cloudburst proportions.

Nevada's principal river, the Humboldt, is formed by the junction of the South Fork, the East Fork, and the North Fork slightly west of the Ruby-East Humboldt Range. The river flows westward and eventually southward to Humboldt Lake and Carson Sink in the west-central part of the State (Fig. 1); hence, for the Ruby-East Humboldt region it is essentially a through-flowing river.

The South Fork rises on the west slope of the middle and southern Ruby Mountains, flows westward, and crosses the southern part of the Elko Range in a narrow, hard-rock gorge before it joins the main stream of the Humboldt River southwest of Elko. The East Fork is formed by the junction of several streams from the west slope of the northern part of the range and crosses the northern end of the Elko Range in a short, steep-sided, hard-rock gorge.

The streams on the east side of the Ruby-East Humboldt Range, excluding Willow and Clover creeks, drain into a large topographic basin east of the range. This basin is subdivided into three smaller closed areas, each containing a dry or intermittent lake, which from north to south are Snow Water Lake, Franklin Lake, and Ruby Lake. Ruby Valley east of the Ruby Mountains is the largest of these closed areas and contains both Franklin and Ruby lakes. Clover and Willow creeks flow around the northern end of the range into the Humboldt River and are the only streams of the east slope which do not drain to an aggrading basin.

GEOLOGIC SETTING

The geology of this region has been described in other papers (Sharp, 1939a, 1939b) and will only be outlined briefly. The Ruby-East Humboldt Range is a horst, faulted on both sides, and tilted westward by

greater displacement on the east boundary fault than on the west (Fig. 3). It consists of a complex of moderately hard and resistant sedimentary, metamorphic, and igneous rocks. Hereafter, these rocks will be referred to as pre-Tertiary, although the igneous intrusions may possibly be early Tertiary.

The basin on the west contains a series of relatively unconsolidated continental deposits of Miocene age—the Humboldt formation.[1] They

FIGURE 3.—*Structure section*

Qal—Quaternary deposits; *Th*—Miocene Humboldt formation; *Pt*—pre-Tertiary rocks.

have a simple structure near the center of the basin but are strongly deformed near the edges. Quaternary alluvium fills the closed basins to the east completely burying the underlying rocks. The range was extensively glaciated in the late Pleistocene.

GEOMORPHIC FEATURES OF THE MOUNTAIN BLOCK

GENERAL STATEMENT

The interior of the range is a mass of deep canyons, rugged peaks, and ridges (Pl. 1, fig. 1). Dissection has been so complete that few vestiges of preceding geomorphic forms are preserved. However, those remnants that are present warrant brief discussion, which perforce must be somewhat speculative.

OPEN-VALLEY STAGE

Many streams on the west slope of the Ruby Mountains notably Ross, Soldier, Cold, Thorpe, Kleckner, North Furlong, and Mahogany creeks—head in broad, open saddles on the range crest (Pl. 1, fig. 2). These saddles are distributed along the crest for 20 miles at elevations of 9200 to 10,400 feet.

Gently sloping shoulders, graded to streams several hundred feet higher than the floors of the modern canyons, have been observed in the upper parts of Long and Mahogany creeks (Fig. 4). They have elevations of 8500 to 9500 feet and are 600 to 1000 feet above the present streams, showing an upstream increase in both height and elevation.

[1] The Humboldt formation has been dated as upper Miocene (Sharp, 1939a, p. 151-154). However, Professor R. W. Chaney has recently informed the writer that the beds near the base of the formation may be as old as lower Miocene.

These shoulders definitely give the impression of being associated with the open saddles on the range crest, and both features are thought to be best explained as remnants of an open-valley stage developed during a pause in uplift of the mountain block. The modern streams flow in

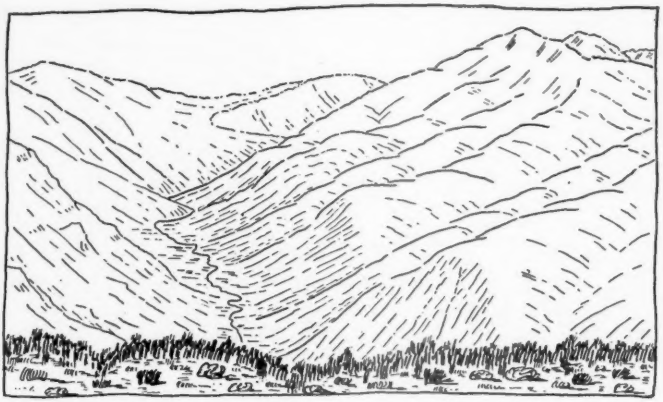

FIGURE 4.—*Open-valley remnants on Long Creek*

Rounded ridges to the right of Long Creek are correlated with the broad saddle on the skyline. (Sketched from a photograph.)

U-shaped, glaciated gorges incised in the floors of the open valleys and following essentially the same westward courses. The height of interstream ridges shows that the open valleys were 1200 to 1300 feet deep. The gradients of these valleys should be less steep than those of the modern youthful streams. However, some of the remnants suggest a gradient as steep if not steeper than the modern streams. This is probably due to westward tilting of the mountain block as it was uplifted (Sharp, 1939b).

It is a logical expectation that pediments would have been cut on the flanks of the range during the interval in which the open valleys were formed. Treads on the various ridges along the west front of the range at altitudes of 7600 to 8500 feet may be remnants of such pediments. However, the open-valley remnants are so far removed from these treads that definite correlations are unwarranted.

RELATIVE POSITION OF RANGE CREST AND DRAINAGE DIVIDE

In many places the crest of the range and the drainage divide are one and the same. In other places, the crest is 1 to 2 miles west of the drainage divide. Soldier, Cold, Thorpe, Talbot, and Lamoille creeks are

good examples of streams which rise east of the crest and flow westward in canyons cut through it (Fig. 5).

At present, the drainage divide is moving westward under the attack

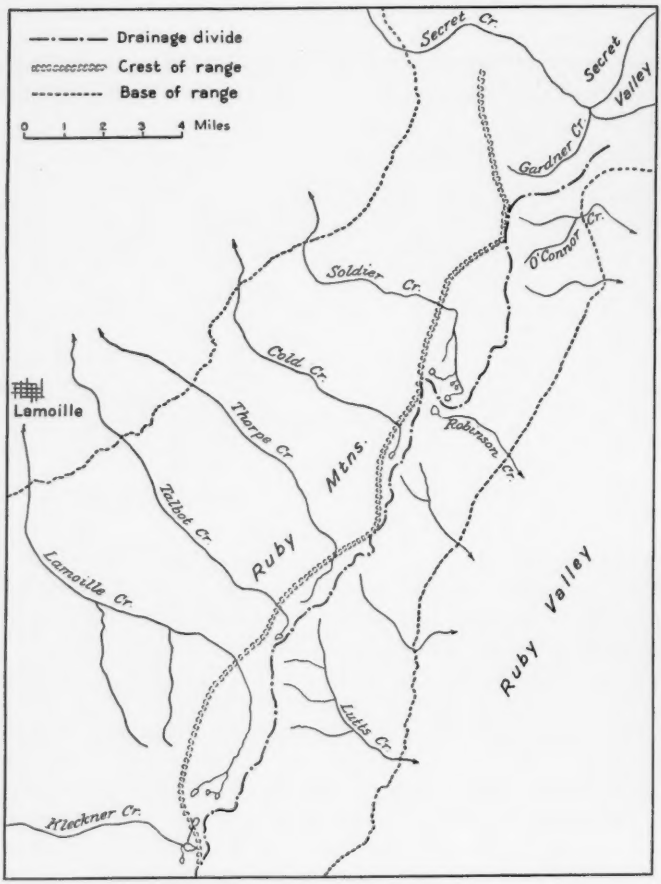

FIGURE 5.—*Map of drainage divide and range crest*
Note the streams which rise east of the crest and flow westward through it.

of short, steep streams on the east face of the range. Many of the open-valley heads form broad U-shaped saddles on the present divide (Pl. 1, fig. 2; Fig. 4). These valleys have been beheaded by eastward-flowing streams. The drainage divide must have been east of the present divide when the open valleys were formed. Why, then, is the crest of

FIGURE 1. RUGGED TOPOGRAPHY AND COMPLETE DISSECTION
Looking south from the north wall of Lamoille Canyon.

FIGURE 2. OPEN-VALLEY HEADS AT CREST OF RANGE
View southward along crest at head of North Furlong Creek.

INTERIOR RUBY MOUNTAINS

FIGURE 1. LEE SURFACE
View northward across South Fork of the Humboldt River.

FIGURE 2. SURFACES AT LEE
View northward. The even skyline is the Lee surface (Surface 2). Surfaces 4 and 5 are also seen where numbered.

FIGURE 3. HEAD OF LAMOILLE CANYON
Alpine character of interior Ruby Mountains.

PEDIMENTS AND INTERIOR RUBY MOUNTAINS

the range in places west of the present divide, and how did such streams as Lamoille, Talbot, Thorpe, Cold, and Soldier creeks obtain passage westward through the crest?

The streams could have taken their anomalous courses by superposition from an overlying sedimentary cover, but this seems to be excluded, for the Miocene Humboldt formation in the adjoining basins, the only reasonably possible sedimentary cover, contains detritus derived from the mountain block. The basin sediments lapped up onto the flanks of the range but never buried it completely. A complete covering of the crucial areas would be required if the streams were to be superposed. Antecedence seems to be eliminated because the available evidence indicates that the range was uplifted as a single rigid block and that the initial drainage of this block was of a consequent type. Headward erosion by the streams is considered the best explanation.

This postulate is supported by the fact that each stream swings southward at its head after crossing the crest of the range (Fig. 5); in Talbot and Lamoille canyons, at least, this curving course in the upper part is known to parallel the strike of the rocks. This suggests a structural control of the stream courses, which should be so if the streams obtained their position by headward migration.

The stage in the history of the range during which this headward migration of westward-flowing streams occurred and its cause are not easily determined. The last major uplift of the range (Pliocene to middle Pleistocene) was marked throughout by greater uplift on the east side than on the west. This increased the effectiveness of the streams on the east side and promoted a westward migration of the drainage divide. The eastward movement of the divide must have occurred prior to this last major uplift.

Evidence presented in another paper (Sharp, 1939b) shows that the range was uplifted by faulting at intervals extending from Miocene to the present. The available evidence indicates that during each of these uplifts the displacement was greater on the east side and that the mountain block was tilted westward so that conditions immediately following favored a westward migration of the drainage divide. Some of the uplifts were separated by extended periods of erosion, and it is postulated that during one of these a balance was reached between the erosional attack from opposite sides, and the divide ceased to migrate. If the period of stability were long enough, the crest and the drainage divide would become one and the same, regardless of their relative positions prior to uplift.

The streams on the east side of the range drain into a series of closed basins; those on the west side, into the Humboldt River which is a

through-flowing stream. Lowering of base level along the Humboldt west of the Ruby-East Humboldt region would rejuvenate the streams on the west slope of the range and give them an advantage over the east slope streams. This seems the most reasonable explanation for the eastward migration of the drainage divide. Therefore, it is postulated that, prior to the last major uplift of the range, some of the larger and more powerful streams of the west slope, rejuvenated by a lowering of base level along the Humboldt River, migrated by headward erosion and drove the drainage divide slightly east of the range crest. Rejuvenation of the Humboldt drainage is a reasonable assumption because, as shown subsequently, that river was rejuvenated a number of times in the Pleistocene, and similar rejuvenations could have occurred at earlier periods. The last major uplift and westward tilting of the range started the drainage divide moving westward once again.

GEOMORPHIC FEATURES OF THE WEST FLANK AND ADJOINING BASINS

GENERAL STATEMENT

The geomorphic forms of the west flank of the range and the adjoining basins have been developed under a régime of exterior drainage. Remnants of pediments, partial pediments, and terraces are well preserved in four areas along the west side of the range, which from north to south are:

(1) A narrow strip, 2 to 3 miles wide, at the base of the East Humboldt Mountains from Secret Pass 13 miles north to Ackler Creek (Fig. 6), hereafter referred to as the Boulder Creek area.

(2) A smaller area just northeast of Lamoille at the base of the Ruby Mountains (Fig. 7). This will be called the Thorpe Creek area.

(3) An area including the tributaries of the South Fork of the Humboldt River, both upstream and downstream from the town of Lee (Fig. 8), to be called the South Fork area.

(4) An area along the base of the Ruby Mountains east of Jiggs (Fig. 9). This will be called the Smith Creek area.

The two northern areas are drained by streams tributary to the East Fork of the Humboldt River, the two southern areas by streams tributary to the South Fork.

In nearly all the areas, remnants of two pediments and three terraces or partial pediments have been recognized. In several places, remnants of a fourth and lower terrace have been noted, and along the South Fork of the Humboldt River, a fifth terrace has been mapped. These surfaces have been numbered successively with the highest as number 1. The number 2 surface which is the best preserved and most extensive

of the series has been named the Lee surface from a large remnant near the town of Lee on the South Fork (Pl. 2, figs. 1, 2). It indicates an extended period of erosion to a stable base level and has been named in

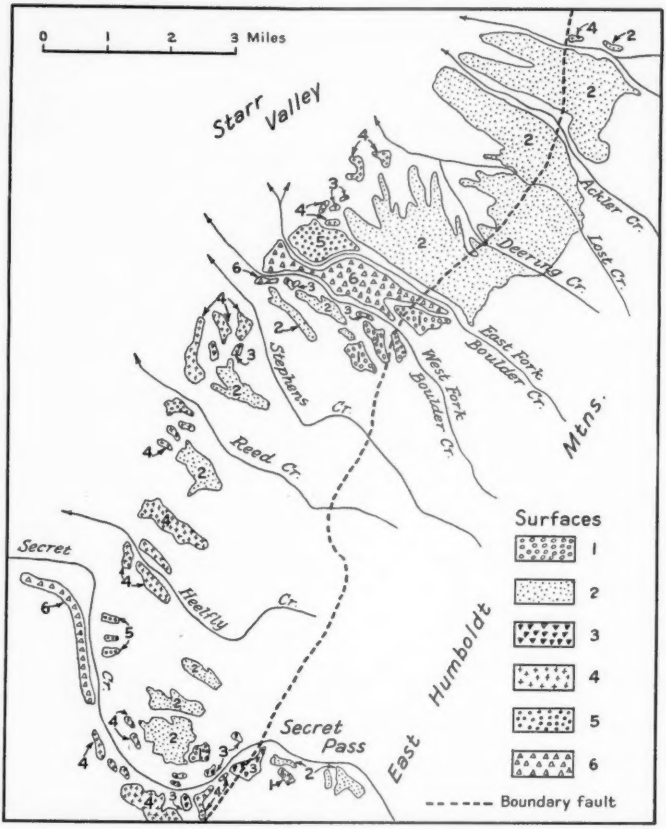

FIGURE 6.—*Map of surfaces in Boulder Creek area*

order to facilitate correlations with neighboring areas in which a corresponding period of stability and erosion may have occurred. The patterns on Figures 6 to 9 represent only the relatively flat parts of the surfaces and not the transition slopes between adjoining surfaces which have been left blank. Some workers prefer to include the transition slopes with either the surface above or below.

DESCRIPTION OF SURFACES

Surface 1 is the highest and presumably oldest surface along the west flank of the range. It was a broad, well-developed pediment, which bevelled deformed Miocene basin deposits and in places extended as much

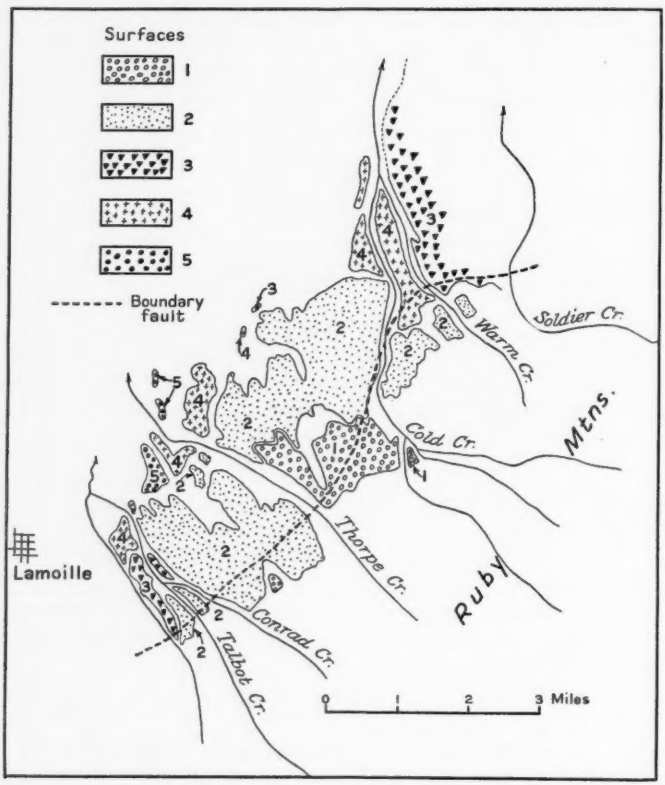

FIGURE 7.—*Map of surfaces in Thorpe Creek area*

as a mile across hard pre-Tertiary rocks on the edge of the mountain block. Surface 1 is represented by a few small, widely scattered remnants, which are mantled by stream gravel and slope-wash detritus. It is highest above stream grade—600 feet—at the mouth of Secret Pass. In most places it is 75 to 150 feet above surface 2 from which it is separated by gentle, debris-mantled slopes.

TABLE 1.—*Heights of west flank surfaces above stream grade* *

	SURFACES						
BOULDER CREEK AREA (Figure 6)	1	2	3	4	5	6	7
East Fork Boulder Creek	x	250	x	x	75	35	
West Fork Boulder Creek	400	270	210		70	x	
Reed Creek		350		150	50		
Heelfly Creek				165			
Secret Creek	600	450	195	125 135 160 165	*95* *125* 55	25	
Gorge of East Fork Humboldt River		520	285	205	100		
THORPE CREEK AREA (Figure 7)							
Warm Creek		x	120	75			
North of Thorpe Creek	x	370 *350* *310* *255* *195*		80			
Thorpe Creek	435–460	360		85 155	65 30 35 45		
Conrad Creek Talbot Creek		175	70	45			
SOUTH FORK AREA (Figure 8)							
Long Creek		240	165 200	80	45	x	
Kleckner Creek North Prong South Prong		240 265	175	*130* 75 110	45 60 65	20	
Pearl Creek		105	50	x	x		
South Fork		315	x	285	85 120 200	55 60	20 35
Gorge of South Fork		440–490			215	115	x
SMITH CREEK AREA (Figure 9)							
Smith Creek		95 195		*40* 35 50 75	15 50		
Dry Creek		105	x	x			
McCutcheon Creek		100	80	x			
Carville Creek	300	x	x	100	30 65		
Toyn Creek	x	x	155	x	x		

* Most of the heights were determined by hand levelling with a Brunton compass, though some were taken from topographic maps. The measurements were made to the top of the surface, and not to the contact between the gravel, which caps the surface, and the underlying bedrock. In nearly all places the overlying gravel has slumped down so extensively that the top of the underlying bedrock surface has been entirely buried. Thus, the heights of the surfaces as listed include from 5 to 25 feet of gravel. The figures are given in groups corresponding to the four areas outlined. A series of figures for any one surface along a single stream represents measurements made on that surface at points progressively downstream. Surfaces which are present at a particular locality but whose height above stream grade is not known are denoted by an X mark. Blank spaces indicate that the surface is not present or has not been recognized. Heights of small intermediate remnants included in the table are in italics. Figures from different streams cannot always be directly compared as the measurements were not made at corresponding positions on the streams. The correlation of these surfaces from area to area and from stream to stream is considered in the text.

FIGURE 8.—*Map of surfaces in South Fork area*

Surface 1 is not preserved on Long Creek (Fig. 8), but if it maintained its usual height above surface 2, which is present, it would be about 400 feet above stream grade on Long Creek. The remnants of the open-

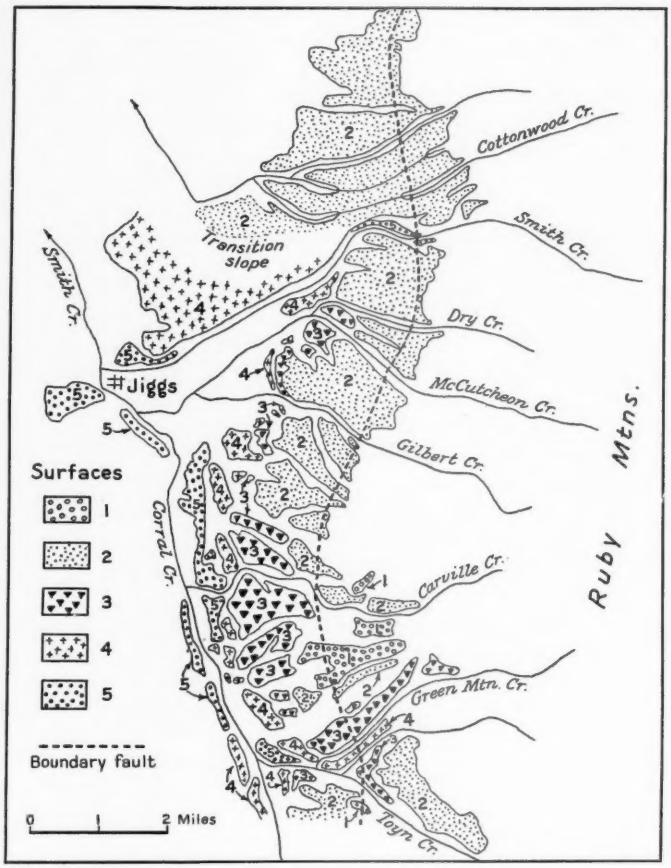

FIGURE 9.—*Map of surfaces in Smith Creek area*

valley stage of the mountain block near the head of Long Creek are 600 to 1000 feet above stream grade. This difference shows that surface 1 and the succeeding surfaces are younger than the open-valley stage of the mountain block.

FIGURE 8.—*Map of surfaces in South Fork area*

Surface 2 (Lee Surface) is a broad, gravel-mantled pediment which bevels deformed basin deposits and in places extends for short distances across the hard rocks of the mountain block. It is the best-preserved and most extensive of the west flank surfaces (Pl. 2, figs. 1, 2; Pl. 3, fig. 2). In the gorges of the East Fork and the South Fork, 15 to 17 miles west of the Ruby-East Humboldt Range, surfaces 450 to 500 feet above stream level have been correlated with surface 2. Along the flanks of the range this surface is highest above stream grade—450 feet—at the mouth of Secret Pass. On the average, it is between 200 and 300 feet above stream grade and in some places even less.

All the surfaces below 2 are terraces or partial pediments.[2] Surface 2 was dissected by stages, and the pauses in downcutting must have been shorter than the time required for the cutting of surface 2, or that surface would have been destroyed.

Surface 3 is represented by narrow terrace remnants along some streams. South of Carville Creek and elsewhere, relatively broad remnants extending from one stream to the next suggest that in places surface 3 was a partial pediment. In the gorge of the East Fork a shoulder 285 feet above stream grade has been correlated with surface 3. Along the flanks of the range its average height above stream grade is approximately 200 feet.

Surface 4 is also represented by terrace remnants, although moderately broad remnants which extend from one stream to the next suggest that in places it was a partial pediment. Surface 4 is best preserved between Reed and Stephens creeks and north of Heelfly Creek (Fig. 6).

Surface 5 is another terrace represented locally by broad remnants that indicate that it was also a partial pediment. Surface 5 is 215 feet above stream grade at the gorge of the South Fork. Its average height above streams near the base of the mountains is about 50 feet. The progressive increase in height of this and other surfaces downstream is discussed in a following paragraph dealing with dissection of the surfaces on the west side of the range.

Surface 6 includes narrow terrace remnants along a number of creeks. This surface was much less extensive than any of the preceding surfaces. It is 115 feet above stream grade at the gorge of the South Fork. Along the streams at the base of the mountains surface 6 is commonly 20 to 25 feet above stream grade.

Surface 7 is represented solely by terrace remnants along the South Fork of the Humboldt River downstream from Twin Bridges (Figs. 2, 8). It is from 20 to 35 feet above river grade at this place.

[2] The surface formed by two or more coalescing terraces along adjacent streams is provisionally termed a partial pediment.

FIGURE 1. SURFACES 4, 5, AND 6
View southward across the South Fork of the Humboldt River near Twin Bridges.

FIGURE 2. SURFACES 2 AND 3 NEAR JIGGS
Looking southward toward the mouth of Gilbert Creek.

SURFACES WEST OF RUBY MOUNTAINS

FIGURE 1. DISSECTED PEDIMENT AT WILLOW CREEK
Moraines (M) of earliest and later Wisconsin glaciation resting on the pediment.

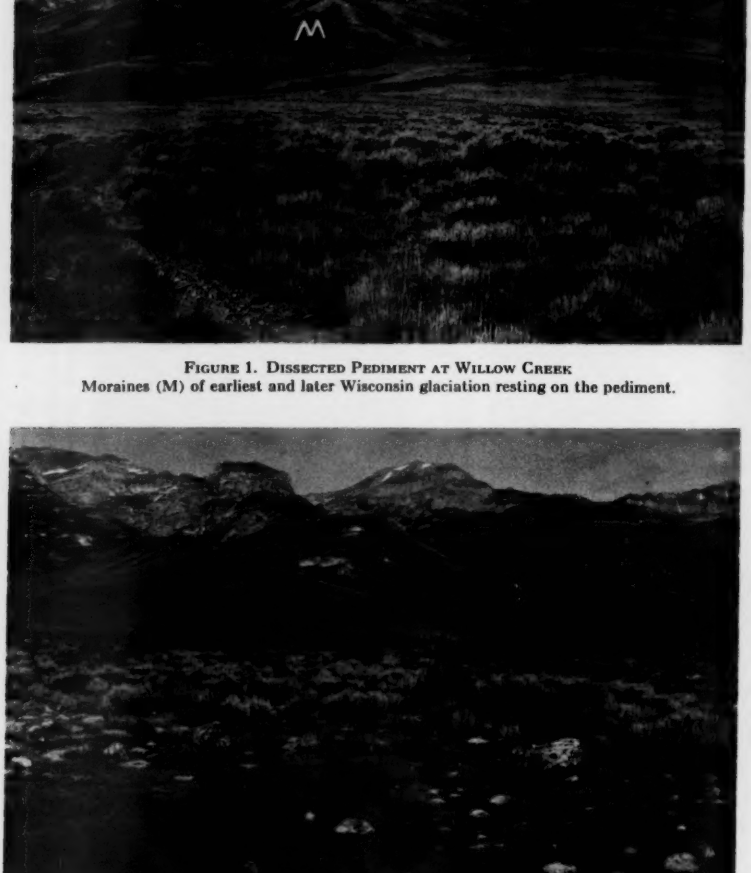

FIGURE 2. PEDIMENT AT STEELS CREEK
The pediment is mantled by rock detritus like that in the foreground.

Most of the interstream area of the basin to the west of the Ruby-East Humboldt Range consists of low cuestas developed on gently dipping Miocene deposits. The uniform height of the cuesta crests plus, in many places, a capping of caliche and gravel suggest that they have been planed off at a common level in some earlier period. Woolnough (1928), Bryan (1938, p. 5-6), and Price (1933, p. 515-516) have discussed the significance of caliche as an indicator of erosion surfaces of low relief. The altitudes of these cuestas are too low to be related to surface 2 except in a few places, and probably one of the lower surfaces, represented at the base of the mountains by terraces and partial pediments, was more extensive westward toward the center of the basin.

IDENTIFICATION AND CORRELATION OF SURFACES

Proper identification and correlation of these surfaces may be questioned because of the range in heights above stream grade and the wide geographic separation of many of the remnants. Surface 2 is easily identified in nearly all localities by its wide extent and excellent preservation. Surface 1 appears as remnants which rise above 2 and can be identified on that basis as it has been found only where 2 is present. The surfaces below 2 are identified more arbitrarily. Surface 2 has been dissected in stages separated by periods of stability during which terraces or partial pediments were developed. Generally three and in some places four terraces or partial pediments can be observed below surface 2; and in these places the distance below 2, the height above stream grade, and the relations to surfaces better preserved on nearby streams are the only means of identification. On streams with a complete series of surfaces from 1 to 6, the identifications and correlations are probably correct. The identifications have a greater chance of being incorrect, the smaller the number of surfaces present.

The high percentage of quartz and quartzite boulders in the gravel mantling surfaces 1 and 2 attracts immediate attention in the field. The predominance of quartz and quartzite boulders is attributed to residual concentration, the less resistant rock types having been destroyed by weathering. Mackin (1937, p. 838-839) has described these relations in some detail. Surfaces younger than 2 do not have a concentration of resistant rock types. This relation provides a further criterion in the recognition of the higher surfaces.

GEOMORPHIC FEATURES OF THE EAST FLANK

GENERAL STATEMENT

The surfaces on the east flank of the range differ from those on the west; they are cut largely on hard rocks, and the climatic conditions

under which they formed were somewhat more arid. Furthermore, they are included within an area of interior drainage and have been formed in part at least with respect to a rising base level.

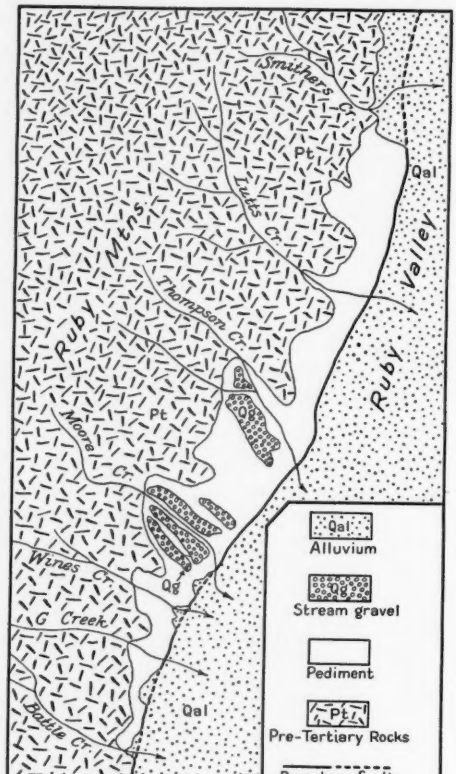

FIGURE 10.—*Map of fault scarp and pediment*
East side of Ruby Mountains.

DESCRIPTION OF SURFACES

A pediment along Willow and Clover creeks (Pl. 4, fig. 1) at the north end of the East Humboldt Mountains is an exception to the generalizations just made, for it is cut on soft basin deposits, and at present Willow and Clover creeks are through-flowing streams draining around the north

end of the range into the Humboldt River. This pediment is dissected to a depth of 100 feet, and at a number of places remnants of a thin mantle of stream gravel are preserved.

From Ralph Creek south to the Polar Star mine, the East Humboldt Mountains are flanked by alluvial slopes which extend up to the base

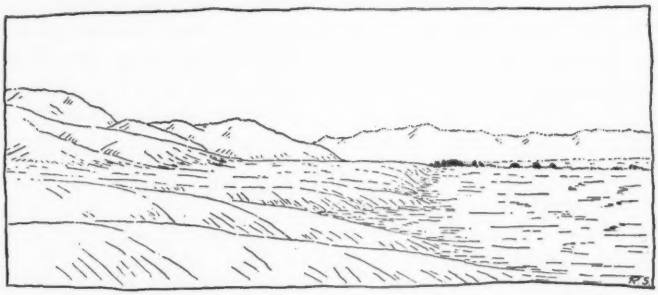

FIGURE 11.—*Dissected pediment, east flank of Ruby Mountains*
Looking north toward Lutts Creek. (Sketched from a photograph.)

of the mountains (Pl. 4, fig. 2). In one or two places outcrops of pre-Tertiary rocks near the base of the mountains suggest that at least the upper half-mile of these slopes actually form a debris-mantled pediment.

The south end of the East Humboldt Mountains is encircled by a broad, bare-rock pediment, dissected to a depth of 5 to 20 feet, and cut across Carboniferous limestone and Pliocene (?) lavas.

The west side of the southern projection of the East Humboldt Mountains, the west flank of the Valley Mountains, and most of the east flank of the Ruby Mountains are bordered by alluvial-covered slopes which do not have the undulatory cross section parallel to the mountain front which typifies a piedmont slope formed by coalescing alluvial fans. The reasonable interpretation is that these slopes are actually debris-mantled pediments. In a few places, notably just south of Sharps Creek, streams cutting through this alluvial mantle have exposed a gently sloping surface cut on pre-Tertiary rocks. The alluvial cover is not over 20 feet thick. Elsewhere, isolated knobs of pre-Tertiary rocks project through the alluvial mantle, substantiating the postulate that the alluvium actually rests on a surface cut on pre-Tertiary rocks.

The pediment on the east flank of the Ruby Mountains is uncovered and dissected between Smithers Creek and Battle Creek (Fig. 10). This surface is cut on the pre-Tertiary limestone and intrusives which compose the mountain block. It is bounded on the east by a fault scarp, 150 to 200 feet high, and on the west by the face of the range (Fig. 11).

A careful search disclosed no fault between the pediment and the mountain face to the west. The pediment is an erosion surface left at the foot of the mountain front as it retreated more or less parallel to itself under the attack of erosive processes. The surface of this pediment has been abandoned by the streams now intrenched below it owing to uplift along the fault to the east. However, it seems likely that the interstream ridges have continued to retreat westward under attack of various erosive agents, although perhaps at a slower rate owing to lack of removal of detritus by the intrenched streams. This and other dissected pediments should not be considered as entirely static forms.

Farther south near Dawley Creek renewed movement on the boundary fault has uplifted a relatively narrow strip of pediment about a quarter of a mile wide and 3 miles long. It is cut entirely on granitic rocks of the mountain block. This surface and that just described are probably sections of the pediment which flanks the entire east side of the Ruby Mountains.

Other small pediment remnants are scattered along the east face of the Ruby Mountains from Battle Creek south to Harrison Pass. These remnants are 50 to 125 feet above stream grade and in most places are bare-rock surfaces not mantled by alluvium. Their dissection is related to changes of base level caused by acceleration in the upward movement of the mountain block and by local changes in stream courses. The remnants are too small for one to attempt to correlate them with each other or with other pediments.

Terraces are so few and of such local extent on the east side of the range that no attempt at description or correlation will be made. In every case there is evidence that the terraces are related to local changes caused by faulting, glaciation, capture, shifting of stream courses, or sinking of the water level of the Pleistocene lakes which filled the basins east of the range.

Since the various stages of erosion represented by pediments and terraces on the west side of the range are related to periods of stability and rejuvenation of the Humboldt River, no attempt will be made to correlate surfaces between the east and west flanks. The pediment at the north end of the East Humboldt Mountains along the east flank is located on streams which eventually find their way into the Humboldt River, but even in this case no correlation with the west flank surfaces seems justified. The alluvium-mantled pediment flanking the east side of the range may have been cut during an interval in which several of the west flank surfaces were being formed.

GRADIENTS OF PEDIMENTS AND TERRACES

Gradients on the pediments and terraces on the west side of the range are 75 to 350 feet per mile. Data for the gradients of surfaces on the east side are much less complete. The dissected pediment near Thompson Creek (Fig. 10) has a gradient of 400 to 500 feet per mile. Other pediments on the east side appear to have correspondingly steep gradients. Gradients on pediments in various parts of western United States have been reported as follows: Bryan (1925, p. 95) 50 to 200 feet per mile in southwest Arizona; Gilluly (1937, p. 322) 70 to 300 feet per mile for the Ajo region, Arizona; Blackwelder (1931, p. 137) 45 to 675 feet per mile—230 feet per mile average—for southwestern United States. Thus, the gradients of the pediments of the Ruby-East Humboldt Range fall within limits set by studies in other parts of western United States.

The causes for diversities of gradients are multiple. Among the more important are: volume of water, amount and coarseness of debris, permeability of underlying rocks, periodicity of rainfall, velocity of weathering, resistance of the underlying rock, and proximity to the mountain slope. The steeper gradients of the east flank pediments compared to those on the west are probably due to smaller streams and the coarser and greater amount of debris shed by the steep east face of the range.

DISSECTION OF SURFACES

GENERAL STATEMENT

Dissection of surfaces along the entire west front of the range is so general and so uniform as to suggest a common origin. Dissection of surfaces on the east side is less extensive and in each case is related to local causes.

DISSECTION OF SURFACES ON WEST SIDE OF RANGE

Surfaces 1 and 2 on the west side extend from the basin block onto the mountain block without noticeable break. The same is true of the lower surfaces, on a smaller scale. Therefore, dissection of these surfaces cannot be due to differential movements of the mountain and basin blocks; it must have been caused by rejuvenation of the Humboldt River drainage. Local, differential movement between the mountain and basin blocks has played a minor role in dissection of the west flank surfaces. Low piedmont fault scarps have been mapped along the west base in a few places. Wherever these faults dislocate erosion surfaces the mountainward parts of those surfaces have been dissected. However, examples of this are so few and so local that it is of minor significance in relation to the more general cause of dissection.

The best available evidence indicates that the mountain block has been

tilted less than 25 minutes westward since the higher pediments were formed. Hence, it is apparent that tilting is also a minor feature.

The South Fork and the East Fork of the Humboldt flow across the Elko Range in narrow, hard-rock gorges, and all the water from the west slope of the Ruby-East Humboldt Range passes through these gorges. Measurements of the heights of various shoulders or terrace remnants in or just upstream from the gorges have brought out some notable relations, particularly at the gorge of the South Fork.

The upland of the Elko Range is a surface of subdued and mature topography which slopes gently toward the South Fork gorge as though it were graded to a former level of the South Fork 450 to 500 feet above the present level. Surface 2, so extensively preserved along the base of the Ruby-East Humboldt Range, cannot be traced continuously to the South Fork gorge, but surface 5 can be traced almost continuously (Fig. 8) and shows a progressive increase in height above stream grade toward the gorge. If surface 2 has a corresponding increase in height, it should be about 450 feet above the present stream at the South Fork gorge. This suggests a correlation between the mature surface of the Elko Range and surface 2. No surface in the Elko Range lower than the mature upland is extensive enough to warrant correlation with surface 2. Furthermore, the mature surface seems better correlated with 2 than with surface 1 because of relative heights above stream grade.

The top of the hard-rock gorge of the East Fork of the Humboldt (Fig. 2) is 520 feet above stream grade. The fact that this and the South Fork gorge are nearly equal in depth, though separated 20 miles geographically, indicates that the respective branches of the Humboldt River were essentially at grade when the cutting of the gorges began. This also explains why surfaces on the west flank of the Ruby-East Humboldt Range have comparable heights above streams which are tributary to different forks of the Humboldt River. Furthermore, the fact that these different streams show the same number of rejuvenations indicates that the changes of base level are related to a common cause. In view of the great amount of Pleistocene and Recent faulting in Nevada, changes in base level may possibly have been caused by faulting somewhere along the course of the Humboldt downstream from the Ruby-East Humboldt region. However, wide-scale warping should also be considered for the following reason.

The height of the west flank surfaces above stream grade increases progressively downstream. This is best shown by surface 5 (Fig. 8) along the South Fork but has also been noted on other surfaces and along other streams. Surface 5 has heights of 83, 121, 198, and 215 feet above stream grade progressively downstream. This increase can best

be explained by broad-scale, progressive warping. Rejuvenation by downstream faulting, uniform uplift, or climatic change would require complex and highly speculative changes in the relations of volume, load, and stream gradients to produce an increasing depth of dissection downstream. Unfortunately, the absolute altitudes and gradients of the surfaces along the South Fork of the Humboldt River are not known, so warping can neither be accepted nor dismissed with certainty.

DISSECTION OF SURFACES ON EAST SIDE OF RANGE

The dissection of surfaces on the east side of the range is related to local conditions. A few cases will be discussed briefly as examples.

The broad pediment at the east base of the Ruby Mountains extending from Smithers Creek to Battle Creek (Fig. 10) is dissected to a maximum depth of 200 feet by the larger streams which flow across it. This dissection is due to uplift by faulting, for the pediment is bounded on the basinward side by a fault scarp, and the depth of dissection is directly comparable to the height of the scarp. Terraces at 50 and 100 feet above stream grade on Lutts Creek indicate that the dissection has been by stages which may be related to separate fault movements.

Robinson Creek (Fig. 2) has dissected the piedmont slope across which it flows to a depth of 100 feet. Two stages in this dissection are shown by remnants of former stream channels. The streams immediately north and south of Robinson Creek show no such dissection; it is clearly a local feature. At present, the waters of Robinson Lake drain into Robinson Creek, though at an earlier period, prior to the last glaciation (later Wisconsin), Robinson Lake was drained to the west by Soldier Creek. The ice of the last glaciation diverted the water of Robinson Lake into Robinson Creek. This additional supply of water has enabled Robinson Creek to trench its piedmont slope.

The dissection of the piedmont slope by Road Creek and nearby streams in the southern part of the Ruby Mountains seems related to postglacial fall of the water level in Franklin Lake.

Willow and Clover creeks, which flow around the north end of the range into the Humboldt River, have dissected a pediment near the north end of the range. Rejuvenation of the Humboldt River or stream capture could have caused this dissection. Dissection of surfaces in other places may be related to glaciation, shifting stream courses, or capture, in each case a local feature.

AGE OF GEOMORPHIC FEATURES

The open-valley stage is definitely older than the Pleistocene glaciation, for dissection of bedrock since the earliest recognized glaciation

(earliest Wisconsin) is only 50 feet. An erosion surface of low relief is preserved under a cover of Pliocene (?) lavas at the south tip of the East Humboldt Mountains and in the Elko Range near Elko. In the East Humboldt Mountains this surface cuts across Miocene basin deposits and Carboniferous limestone. In places, low rounded hills of Carboniferous limestone, 200 to 300 feet high, project through the lava covering. Since this surface is buried by Pliocene (?) lavas, we may speak of it as a Pliocene (?) surface. If the open-valley stage is related to the same period of erosion, it is probably Pliocene. However, at no place within this area can this relationship be proved, and it is entirely possible that the surface under the lavas is older than the open-valley stage, although it does not seem likely that the reverse is true.

As outlined in another paper (Sharp, 1939b), the last major uplift of the range occurred between the late Pliocene and middle Pleistocene. The open-valley stage is either somewhat older than this uplift or was formed during a pause in its early stages. Upon the basis of the evidence cited the open-valley stage appears to be Pliocene, most likely middle or late.

The eastward migration of the drainage divide probably preceded the last major uplift of the range because no sufficiently extended erosion has occurred since. At the time of the open-valley stage the drainage divide was east of the present divide as shown by the beheaded open-valley remnants. The eastward migration may have occurred either during development of the open-valley stage or during the erosion interval represented by the surface under the Pliocene (?) lavas.

Glacial drift of both the earliest Wisconsin and the later Wisconsin glaciations (Sharp, 1938) rests on the pediment along Clover and Willow creeks on the east side of the range (Pl. 4, fig. 1). This surface must be older than earliest Wisconsin but it may still be as young as Illinoian or the beginning of the Wisconsin. The pediment along the east side of the Ruby Mountains near Thompson Creek (Fig. 10), judging from its dissection and general appearance, is at least as old. No glaciers moved far enough down the canyons in this part of the range to permit a relationship between the pediment and moraines to be established. This pediment is younger than the last major uplift of the range. It is probably older than the Wisconsin glaciation but not older than middle Pleistocene.

Earliest Wisconsin glaciers moved out onto the piedmont slope along the west flank of the range at Lamoille, Seitz, and Rattlesnake creeks. The moraines left by these glaciers rest upon surfaces not more than 25 feet above stream grade. The surface upon which the drift rests at the mouth of Lamoille Canyon appears to be either surface 5 or 6. If this interpretation is correct, the surfaces from 1 to 5 or 6 are older than

early Wisconsin, and the surfaces below 5 or 6 are younger, probably later Wisconsin or Recent. The gravel which mantles surface 4 along the South Fork is more deeply stained and more extensively weathered than earliest Wisconsin drift of about the same composition. This strengthens the interpretation that surface 4 and the higher surfaces are older than the earliest Wisconsin, although, judged from their state of preservation, they are probably no older than middle Pleistocene. The pediments and terraces on the west side of the range were probably formed in the latter half of the Pleistocene and early Recent.

ORIGIN OF PEDIMENTS

The origin of pediments remains one of the foremost problems of geomorphology. Gilbert (1877, p. 126-132) is credited with the initial recognition and description of one type of that group of erosion surfaces which we now call pediments. Some geomorphologists believe that they are carved dominantly by lateral planation of streams. Gilbert (1877, p. 126-132) suggested this origin, and it is supported by Johnson (1931, 1932a, 1932b), Blackwelder (1931), and Field (1935). Paige (1912) was inclined toward this view, and Mackin (1937) is one of its latest and most enthusiastic adherents.

Bryan (1923, 1925, 1935-1936, 1936) maintains that in many areas lateral planation is dominant, particularly in the early stages of the cycle, but that it is considerably less effective as the cycle progresses and may be subordinate to weathering, rain wash, and rill wash in the later stages. Lawson (1915) would seemingly emphasize weathering and rill wash as more important than lateral planation. Davis (1930, 1933, 1936, 1938) favors the process of "backwearing" (weathering, rain wash, and rill wash) aided by "downwearing" (downcutting by streams) of the mountain block as the more significant factors in pedimentation, the relative efficacy of "backwearing" and "downwearing" being dependent upon the initial form and stage of the cycle. Gilluly (1937, p. 345-347; 1938, p. 123) states that rill wash and weathering have been more effective than lateral planation in forming the pediments around the Little Ajo Mountains of southwestern Arizona, an area in the mature stage of the cycle. Rich (1935) favors wasting (weathering and transportation) and sheet washing as the most essential factors in pedimentation.

McGee (1897) long ago suggested that pediments were the result of sheetfloods. This view has not found ardent supporters in recent years, although some workers, particularly Davis (1930, 1933, 1938) and perhaps Rich (1935), tend to think of sheetfloods or related phenomena as having a part in shaping and grading pediments after they have been

formed by other means. Stheeman (1932, p. 1-17) suggests that the mountain or valley slopes waste away chiefly by weathering, and the detritus so derived is moved across the "arena" (pediment) by "flood sheets" and creep.

A review of the studies of pediments in widely separated regions brings the conviction that different processes of pedimentation are dominant under different climatic, topographic, and geologic conditions. The relations in the Ruby-East Humboldt region are such that pediments developed under somewhat different conditions can be compared, though the degree of contrast is not so great as could be desired. These differences may be outlined briefly.

The west flank of the range is included in an area of exterior drainage; the east flank drains to a series of hydrographically closed basins which contain aggrading playas. For this reason the west flank surfaces have been graded to a stable or progressively lowered base level, and the east flank surfaces to a slowly rising base level. Bryan (1936, p. 769-772; Bryan and McCann, 1936, p. 148-152) has given the most complete analysis of the effects of various types of base level on pedimentation, and reference should be made to those papers for details.

Most of the storms in this region come from the west, and, since the crest of the range is high enough to cause most of the precipitation to fall on the west slope, the area east of the crest lies in a rain shadow. In addition, the west slope streams have much larger drainage areas. For these reasons the ratio of permanent to ephemeral streams is greater on the west than on the east side, and the west slope streams are larger and more constant in flow.

The term pediment as now used (Johnson, 1931; Bryan, 1936, 1938; Mackin, 1937) includes surfaces like those west of the range, which are cut mostly on the soft deposits of the basin block and only in small part on the mountain block. The east flank pediments, with one exception, are cut entirely on the hard rocks of the mountain block. This difference is fundamental and accounts for some of the differences noted between the pediments on opposite sides of the range. It is due in large part to the structural relations and to the exterior drainage of the west flank as contrasted to the interior drainage of the east flank.

Remnants of pediments on the west flank extend as far as 5 miles from the foot of the mountain slope, and the undissected surfaces were probably even more extensive. The east flank pediments are much narrower, at least as exposed, and seldom extend more than 1½ miles from the mountains. The west flank pediments have gentler gradients and are more nearly smooth than those of the east side. The pediments of the west side are mantled by a comparatively uniform cover of stream gravel;

those of the east side have only local patches of stream gravel and are either bare rock or mantled by alluvium, in large part slope wash or detritus developed *in situ*.

It seems reasonable to conclude that these differences are attributable to differences in the efficacy of the several processes of pedimentation as determined by different geologic, climatic, and topographic conditions. The facts that terraces cut largely by lateral planation along adjacent streams coalesce to form partial pediments; that the largest and smoothest areas of pediment are adjacent to the largest streams; that the surfaces indent the mountain front along the streams and are restricted in areas of hard rocks suggest that the west flank pediments have been cut dominantly by lateral planation of streams. A cover of stream gravel on a surface is not proof that the surface was cut by lateral planation; it may merely show that a stream has migrated over the surface which actually may have been cut by other processes. Of the several features cited, the formation of partial pediments by coalescing terraces, obviously cut by lateral planation as shown by meander scars and related features, is considered the most convincing argument favoring the lateral planation theory. The detailed evidence favoring pedimentation by lateral planation of streams has been given by Mackin (1937, p. 826-828, 834, 877-878).

At the base of the mountain slope the west flank pediments lap over onto the hard rocks of the mountain block. In these places the cover of stream gravel is restricted to patches along the streams which cross the pediment, the gradients of the surfaces are steeper, the surfaces are less smooth, and the influence of differential rock hardness on weathering is apparent. The lateral planation of streams appears to have been less effective owing to increased rock hardness, and the work of weathering, rain wash, and rill wash on the interstream areas is proportionately more effective. These relations demonstrate what might be expected—that lateral planation is more effective on soft than on hard rocks. The areas between streams not attacked by lateral planation must be reduced wholly by local processes. Furthermore, if local processes are able to reduce hard rocks, their ability to reduce soft rocks cannot be dismissed. It seems likely that the broader the surface the greater the time and opportunity for processes other than lateral planation to act. Therefore, it seems logical to conclude that, even though lateral planation is dominant along large permanent streams where they flow on soft rocks, local processes such as weathering and rill wash are also effective.

The relatively narrower pediments on the east flank of the range may be grouped into three classes: (1) Pediments exposed and dissected by rejuvenation of streams either by faulting or by some other less common

cause; (2) pediments which are covered by a veneer of alluvium and whose presence is inferred from isolated outcrops and exposure by local dissection; (3) bare-rock pediments which are slightly dissected and which show no evidence of ever having been covered by gravel or alluvium.

The first class includes the well-exposed pediment extending from Smithers Creek to Battle Creek along the east base of the central Ruby Mountains (Fig. 10) and the pediment at the north end of the East Humboldt Mountains along Willow and Clover creeks. These pediments are dissected to depths of 50 to 200 feet. The dissection in the first case is related to faulting and in the second to rejuvenation of streams flowing into the Humboldt River. The Ruby Mountains pediment is cut entirely on the hard rocks of the mountain block, and the East Humboldt pediment almost entirely on soft basin deposits. The Ruby Mountains pediment has an uneven surface upon which low residuals of resistant rock rise above the general level, and in many places it is a bare-rock surface. Elsewhere, it is covered by a thin veneer of slope wash or residual material, except along the major streams where it is mantled by stream gravel. The East Humboldt pediment is smoother and mantled by stream gravel.

Pediments formed chiefly by weathering and related processes compared to those formed chiefly by lateral planation are less smooth, show notable relations to the resistance of the underlying rocks, show only minor indentations of the mountain front along stream courses, and are largely bare or mantled by slope wash or residual detritus.

A comparison of the various features of the two surfaces just described suggests that lateral planation has been more effective on the surface cut on soft rocks despite the fact that the streams crossing the hard-rock pediment are greater in size and number. Thus, lithology appears to outweigh stream size in determining the relative efficacy of the processes of pedimentation in the particular examples considered.

Most of the piedmont slope east of the range as indicated by isolated outcrops and in a few places by local stream dissection is an alluvium-mantled surface bevelling the hard rocks of the mountain block. Following Lawson's analysis (1915), this surface is a pediment, graded to a rising base level, which has been left at the foot of the mountain front as it retreated more or less parallel to itself under the attack of weathering and rain and rill wash. The writer would join Bryan and others in adding lateral planation by streams to the above processes. This surface is undoubtedly modified by the scour and fill action of the streams which flow across it as they shift their courses. Furthermore, it is extended back into the mountain block along stream courses by the lateral erosion of these streams. However, the major work of the streams

after they emerge from the mountain block appears to be largely that of transportation and only in minor part that of erosion.

As pointed out by Lawson (1915, p. 37) and Davis (1933, p. 223-224), the surfaces of the second group—alluvial veneered pediments—barring climatic or diastrophic change, will be mantled by alluvium until late in the erosion cycle when the amount of detritus supplied by the range is too small to cover completely the surface as it is formed. At that time the mountainward part of the surface will be left bare. According to Davis (1933, p. 219-222; 1936, p. 707), sheetflood robbing may uncover parts of the previously buried surface late in the cycle. However, the Ruby-East Humboldt Range is still so youthful that there is not the slightest evidence of sheetflood action along its flanks. In addition, the geologic and climatic conditions are not particularly favorable for sheetfloods. Pediments of this type can be stripped of their alluvial cover by rejuvenation owing to faulting or some other cause, as exemplified by the pediment of that nature already described.

The third class of east flank pediments is represented by a single example—the bare rock, slightly dissected pediment which encircles the south tip of the East Humboldt Mountains. In detail this surface appears relatively uneven and rough with an average relief of 20 to 40 feet. It is crossed by a number of shallow, narrow-floored, detritus-filled stream channels which form a dendritic pattern and which are separated by low rounded divides of bare rock. This pediment is concave in a section parallel to the mountain front, and this concavity is probably a reflection of the coalescent drainage (Gilluly, 1937, p. 335).

A series of processes somewhat like those outlined by Bryan (1935-1936) and Davis (1933, p. 215; 1936, p. 710; 1938, p. 1297) may be considered as having a part in forming this pediment. The streams are ephemeral and run only in times of flood. At present they are largely agents of transportation engaged in carrying detritus brought to them from the mountains and from the interstream areas by rill and rain wash. These streams are able to scour their beds to only a minor degree, owing to the great amount of detritus which they carry. Undoubtedly, at times of especially heavy floods these streams do scour their beds. However, the interstream divides, rounded and deeply disintegrated, are probably being worn down at a rate comparable to the scouring of the stream channels. This situation will prevail until the detritus supplied from the mountains and interstream divides is insufficient to prevent the streams from scouring their beds more deeply. A delicate balance must exist between the processes so that at all times the pediment has a relief fitted to the climatic conditions and rock types involved. The lack of meanders, undercut banks, and oversteepened slopes, and the narrow floors of the

stream channels would seem to indicate that lateral stream corrasion is only a minor process, though the floods of water which pass down the channels must gnaw at their banks to some degree, like any moving mass of water seeking to obtain a wider channel. The concavity of the pediment transverse to the stream channels cannot be used as an argument against lateral planation, however, because lateral planation might take place along the individual channels which are part of a dendritic system and at the same time produce a concave pediment. In brief, the pediment at the south tip of the East Humboldt Mountains is thought to have been developed by weathering and transportation by rain wash, rill wash, and streams aided by some lateral and downward erosion of the streams.

We may ask with Gilluly (1937, p. 343) if pediments of this type may not have been "born dissected". The field evidence in this particular case is not convincing, for rejuvenation of the streams cannot be dismissed with certainty; but the conception that at least some pediments have always had a low relief is worthy of consideration.

This surface has been developed on a low subdued part of the range where the streams are ephemeral and the detritus supplied by the mountains does not form an alluvial cover for the whole surface. The pediment is probably formed not only by the retreat of the mountain front but also by "downwearing" of the mountain block under the attack of weathering and corrasion by the transporting agents. It differs from the pediments heretofore described in this article in its form and mode of origin and resembles those described by Davis (1938) on broadly upwarped or slowly uplifted masses which have low initial relief. Thus, in an area of relatively hard rocks, ephemeral streams, and low relief, the processes of weathering and transportation by rill wash, rain wash, and streams, with only minor lateral erosion appear to dominate. It is possible that as a mountain mass is reduced by erosion its pediments arrive at a stage where they resemble the surface just described. These pediments could be dissected, so to speak, without a diastrophic or climatic change, as already noted by Gilluly (1937, p. 343) and Rich (1935, p. 1023). In a sense a climatic change does occur as the mountain mass is reduced, for, in the Great Basin, streams once permanent may become ephemeral if the range is greatly lowered by erosion. From the foregoing discussion it appears that the form and nature of pediments and the processes producing them depend in part upon the stage of the erosion cycle. The east face of the range is considerably higher and steeper than the west slope. This may explain why the east flank pediments, although relatively narrow, have extended somewhat farther back onto the mountain block than the west flank surfaces.

In the field the work of rills and small streamlets at the base of the mountain front in the interstream areas is impressive. The larger streams issuing from the mountain block do cut laterally to some degree, but the arc over which they swing appears limited on the average to 60

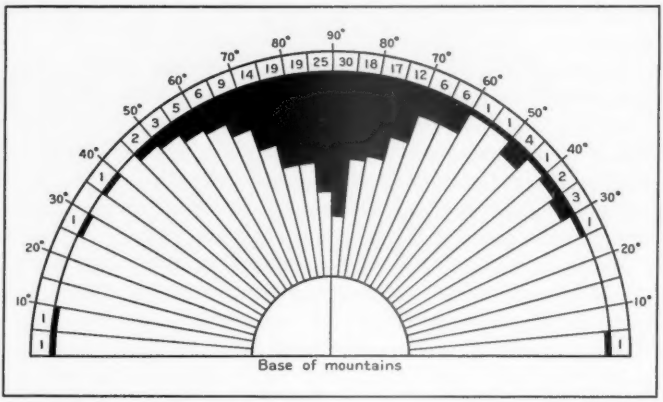

FIGURE 12.—*Plot of angles between stream courses and base of mountains*
Number of streams in each 5-degree interval is recorded just inside the outermost circle.

or 70 degrees. In Figure 12 the angle that stream courses make with the base of the mountain block has been plotted for over 200 major stream courses of the Ruby-East Humboldt Range. The base of the diagram represents the base of the mountain block. Over 90 per cent of the streams make angles of 50 degrees or more with the mountain front. There seems no reason why the density distribution of streams would have been much different in the past. Assuming that the plot (Fig. 12) represents the life history of the average stream, an assumption supported by field observation, lateral planation would be dominant in approximately 40 per cent of the area of Figure 12, and in the remaining 60 per cent other processes would be dominant, although in neither case would any of the processes be wholly excluded. A mountain mass can be cut back by adjacent streams which swing over arcs of 60 to 70 degrees, but the base of the mountains would have a jagged "sawtooth" trace which is not observed in the field. The points of interstream ridges and spurs are cut back dominantly by the attack of weathering and various types of wash including rain and rill wash, so that the range front maintains an essentially linear trace with minor indentations along the streams. Figure 12 shows that only a few of the spurs are trimmed back

by lateral stream erosion parallel to the mountain front. Furthermore, the small gullies on the interstream areas are shallow and narrow bottomed and show no evidence of lateral erosion. No features in these interstream areas resemble the miniature rock fans described by Johnson (1932a, p. 399; 1932c, p. 546), probably because the geologic and climatic conditions in this region are not comparable to those of the areas which he describes.

The data for Figure 12 were taken from both flanks of the range and represent predominantly permanent streams in areas of hard rock. The analysis shows that the retreat of the faces of this particular range is due approximately 40 per cent to lateral erosion by major streams and approximately 60 per cent to weathering and the various types of wash.

The effects of past climatic conditions different from those of the present cannot be evaluated in this region. The late Cenozoic in the Great Basin has been a time of generally increasing aridity. (*See* references in Sharp, 1939a.) However, in at least part of the Pleistocene more water was flowing from the range, and the general climatic conditions may have been more humid. As shown later, the pediments of this region date from the latter half of the Pleistocene; hence, climatic conditions at the time they were developed may have been more humid, and lateral planation may have been more effective, but the relic features of the surfaces give no indication of this.

The conclusions reached as to the formation of pediments under the various geological, topographic, and climatic conditions of the Ruby-East Humboldt region are as follows:

(1) Pediments are formed by lateral planation, weathering, rill wash, and rain wash. The relative efficacy of these various processes is different under different geologic, topographic, and climatic conditions.

(2) Lateral planation is most effective along large permanent streams and in areas of soft rocks.

(3) Weathering, rill wash, and rain wash are most effective in areas of ephemeral streams, hard rocks, and a low mountain mass.

(4) All variations from pediments cut entirely by lateral planation to those formed entirely by the other processes are theoretically possible, although in this area the end members of the series were not observed and perhaps do not actually exist in nature.

The above outline contains nothing startlingly new or different from suggestions advanced heretofore, but an attempt has been made to evaluate the various processes of pedimentation. As emphasized particularly by Bryan (1936, p. 775; Bryan and McCann, 1936, p. 149), the efficacy of the processes must change as the cycle progresses, for newly uplifted

mountains of considerable height are likely to have permanent streams powerful enough to erode laterally once they reach grade. The same mountains in a later stage of the cycle when reduced to lower height may have ephemeral streams and conditions relatively more favorable for the other processes of pedimentation.

SUMMARY

Remnants of a former open-valley stage within the mountains, 600 to 1000 feet above present stream grade, indicate a pause in the uplift of the range, probably in the middle or late Pliocene.

In places the present drainage divide lies east of the range crest. This anomalous condition is related to an interval of erosion prior to the Pliocene-Pleistocene uplift of the range, and more particularly to rejuvenation of the Humboldt River drainage during that interval.

On the west flank of the range and in the adjoining basin, seven surfaces have been recognized and mapped. The two highest surfaces are pediments, the other 5 are terraces or, locally, partial pediments. These surfaces range from 15 to 600 feet above stream grade. They are cut largely on soft, deformed Miocene basin deposits and locally on the hard, pre-Tertiary rocks of the mountain block. They have been formed under a régime of exterior drainage.

A large part of the east side of the range is flanked by a narrow pediment cut on the hard rocks of the mountain block and largely covered by alluvium. This pediment has been exposed in places where the drainage has been rejuvenated by local causes. Also on the east side of the range are remnants of a pediment cut on soft Miocene basin deposits, and the southern tip of the East Humboldt Mountains is encircled by a bare-rock pediment which gives evidence of never having been buried by alluvium. The various surfaces on the east side of the range have been cut under a régime of interior drainage to aggrading basins.

Gradients of surfaces on the west flank of the range are 75 to 350 feet per mile. Gradients on the east flank surfaces are steeper, and, where determined, are 400 to 500 feet per mile. These steeper gradients are attributable to smaller streams and coarser and greater amounts of debris shed by the mountain block. The surfaces on the west have been dissected in stages by rejuvenation of the Humboldt River drainage caused by faulting downstream from the Ruby-East Humboldt region or by broad-scale warping. The dissection of surfaces on the east side is related to local causes such as faulting, capture, glaciation, and falling water level of the lakes in the basins east of the range.

The relations of the pediments and terraces on the east and west sides of the range to drift of the Wisconsin glaciation, and their state of preservation, indicate that they probably date in the latter half of the Pleistocene and the Recent.

The origin of the pediments on the opposite sides of the range formed under somewhat different conditions is considered, and it is concluded that the Ruby-East Humboldt pediments were formed by lateral planation, weathering, rill wash, and rain wash, and that the relative efficacy of these various processes is controlled by the geologic, topographic, and climatic conditions. Lateral planation is most effective along permanent streams and in areas of soft rocks. Weathering, rill wash, and rain wash are most effective in areas of ephemeral streams, hard rocks, and a low mountain mass. Variations from pediments cut dominantly by lateral planation to those formed dominantly by weathering, rill wash, and rain wash, are described.

Upon analysis the retreat of the fronts of this particular range are found to be caused approximately 40 per cent by lateral erosion by streams and approximately 60 per cent by other processes, chiefly weathering and various types of wash.

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University of Illinois, Urbana, Illinois.

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SOUTH BANK OF CANAL, VERO, FLORIDA

(1, 3) Human foot bones in the Melbourne bone bed; (2) Scapula of deer and bone implements; (4) Anastasia formation; (5) Van Valkenburg bed; (A-A') Original soil line.

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EARLY MAN IN AMERICA
INDEX TO LOCALITIES, AND SELECTED BIBLIOGRAPHY

BY E. H. SELLARDS

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ABSTRACT

The writer has assembled the principal results from the investigations of early man made in America, especially North America, from 1839 to 1939. Special attention is directed to associated vertebrate faunas and geologic conditions. A selected bibliography and index to localities in North America are given. It is concluded that man in America was contemporaneous with several vertebrate genera and species now extinct. Among extinct mammalia regarded as associated with man on the basis of more than one occurrence and on observations by more than one worker are elephant. mastodon, camel, horse, bison, sloth, armadillo, glyptodont, tapir, dire wolf, sabre-tooth tiger, peccary, beaver, deer, and cave bear. A considerable number of other extinct species of mammals, birds, and reptiles, based on observations at one or more localities, are probably to be included as associates of man. Human materials have been found in unmistakable association with these animals under varied geologic conditions such as in stream terrace, cave, loess, peat, and lake deposits. Some of the extinct animals associated with man, formerly regarded as index fossils of the Pleistocene, appear to have continued their existence into relatively late geologic time. The supposition that all species with which man is associated continued into the Recent epoch is not justified. Additional information on the time of extinction of these animals and on the age of human remains found in association with them has been obtained in recent years from a study of physiographic features, particularly stream terraces. These observations are in agreement with the conclusion derived from a study of the fossils that man reached America previous to the close of the Pleistocene period.

INTRODUCTION AND ACKNOWLEDGMENTS

The problem of early man in America has been before geologists and anthropologists for a century. Extended discussions have followed reports of human remains or artifacts found in association with extinct animals or under other conditions believed to indicate antiquity. At the time of the founding of the Geological Society of America, 50 years ago, such reported occurrences evoked no great surprise. A good summary of the prevailing opinion of that time may be obtained from McGee's paper (1888). Subsequently, doubt as to the authenticity of the discoveries of early man arose accompanied by vigorous opposition to the idea of early man in America. The term early man is here applied to human relics of some appreciable antiquity in a geologic sense.

One who follows the discussions on this subject during the past century will find (1) approximately 30 years following Koch's discoveries, with few important finds other than that of Dickeson in Mississippi; (2) about 20 years, or until 1889, of fairly general acceptance of the idea of early man in America based on relatively few discoveries, among which, however, were some, as at Trenton, New Jersey, that seemed at the time well authenticated; (3) 25 or 30 years during which the authenticity of all claims of early man were vigorously opposed by some geologists and anthropologists; and (4) the more recent period during which discoveries of human remains or implements in association with extinct animals have been made with greatly increased frequency. During this latest period increased attention has been given to the subject by geologists and anthropologists which accounts in part at least for the increased frequency of such discoveries.

In the course of a century of discussions, in part highly controversial, the literature on this subject has become extensive and so involved as to encourage neglect. The purpose of this paper is to present an index to all localities of reported finds in North America and to cite the principal literature on each locality. Four of the more recently discovered localities in South America are briefly discussed.

The writer is indebted to all who have published on this subject and especially to a great many workers in this field who, through correspondence or otherwise, have aided in checking locality references. Special acknowledgment is made to Charles Amsden, Ernst Antevs, Barnum Brown, Kirk Bryan, R. P. Conkling, H. J. Cook, Samuel Eddy, M. R. Harrington, Frank C. Hibben, E. B. Howard, A. E. Jenks, F. H. H. Roberts, Jr., E. B. Sayles, C. B. Schultz, G. G. Simpson, H. T. U. Smith, Clinton R. Stauffer, and W. D. Strong and to Louis Dixon who has helped in checking the bibliography. The following publications containing

bibliographies on this and related subjects have been consulted in connection with the preparation of this bibliography: Fischel, H. E. (1939); Howard, E. B. (1935); Osborn, H. F. (1936); Roberts, F. H. H., Jr. (1936a); Wormington, H. M. (1939); Bibliography of North American Geology, United States Geological Survey, Bulletins 746, 823, 834, 858, 869, and 892.

The following index to localities of reported occurrence of early man in North America is arranged by countries and states. For each locality there is given: Location, reference to literature, and comments. The intention has been to include all localities in which human materials are reported to have been found associated with extinct animals or in deposits that appear to be of an age equivalent to those that elsewhere contain extinct animals. A few localities, included for convenience of reference, probably do not meet these requirements. On the other hand, some localities doubtless have been overlooked that should have been included. The present location of collections is given when known.

CANADA

MANITOBA

Valley River.—Locality Lake Agassiz beach near Valley River. Literature: Tyrrell (1890); Johnston (1933).

Johnston was unable to verify the presence of artifacts in the gravels.

SASKATCHEWAN

Mortlach.—Locality near Mortlach. Literature: Howard (1939a); Roberts (1939).

Artifacts including Folsom and Yuma points were found associated with bison bones in "blow outs" near Mortlach. The age is indeterminate.

CUBA

ORIENTE

Caleta Cavern.—Locality about 16 miles southwest of Punta Maisi in the easternmost part of Cuba, discovered, 1915; announced, Harrington, 1921. Literature: Harrington (1921).

Bones of the ground sloth *Megalocnus* were found in kitchen midden refuse. Association with human relics is probable but not certain. A similar find was made in a rockshelter near Portales de Guane in the Province of Pinar del Rio near the opposite (western) end of Cuba.

MEXICO

FEDERAL DISTRICT

Peñon.—Locality Peñon de los Banos in the Valley of Mexico about 2½ miles east of Mexico City, discovered January, 1884; announced, Barcena, 1885. Literature: Barcena (1885; 1886a; 1886b); Barcena and Antonio del Castillo (1886); Boule (1923, p. 407); Cope (1895, p. 594); Hrdlička (1907, p. 32); Newberry (1886).

Fresh water deposits described by Newberry as travertine contain part of a human skeleton. Elephant remains were found nearby in strata interpreted by Barcena as of the same age as that containing the human remains.

UNITED STATES

ARIZONA

Whitewater Creek.—Locality on Whitewater Creek at and near Double Adobe School, 12 miles northwest of Douglass. Principal literature: Antevs (1937b, p. 129-132; 1937c, p. 335); Wormington (1939, p. 45-46).

According to Antevs (personal communication) the artifacts occur with or below bones of horse, bison, camel, dire wolf, elephant, and other mammals not yet determined. Artifacts of similar type have been found at other localities in this region in sand and gravel deposits and old stream courses, overlain by clays and other deposits similar to those of the Whitewater Creek locality (Sayles, letter of July 8, 1939). The collections are at the Gila Pueblo, Globe, Arizona.

CALIFORNIA

Angeles Mesa.—Locality one-third mile west of the Angeles Mesa drive and 300 yards south of the Pacific Electric Airline near Los Angeles, discovered, March, 1924; announced, Stock, 1924. Principal literature: Hay (1927b, p. 175); Merriam (1924); Stock (1924).

Human remains including at least 6 individuals and 1 or 2 artifacts were encountered in excavating at depths of 19 and 23 feet. No associated vertebrate fossils were found. A camel bone and a horse bone were found at a nearby locality in deposits that may or may not be a continuation of the deposits containing the human bones. The collections are in the Los Angeles Museum of History, Science, and Art.

Borax Lake.—Locality in Borax Lake, one mile north of Manakee, Lake County. Principal literature: Harrington (1938a; 1938b); Wormington (1939, p. 46-47).

Artifacts were found in a fossil alluvial cone to a depth of 10 feet. Folsom culture was found near the surface underlain by pre-Folsom culture including short unspecialized pestles and metates consisting of rough slabs showing slight grinding but no shaping (Harrington, letter of August 21, 1939). The collections are at the Southwest Museum, Los Angeles, California.

Calaveras.—Locality at Bald Hill, one-half mile northeast of Altaville in the southwestern part of Calaveras County, discovered about 1866. Principal literature: Becker (1891); Blake (1899); Boutwell (1911); Hay (1927b, p. 225); Holmes (1899, p. 623-641; 1901; 1919, p. 61); Hrdlička (1907, p. 21); Keith (1929, p. 471-473); Kollman (1884); Lindgren (1911); Merriam (1936, p. 1315); Schmidt (1872, p. 253-259); Sinclair (1908); Whitney (1880); Wright (1890, p. 563).

This much discussed skull is in the Peabody Museum of Natural History, Harvard University.

Lake Mohave.—Locality about 140 miles northeast of Los Angeles, discovered, December, 1934; announced, Campbell, 1936. Principal literature: Amsden (1937); Antevs (1937a; 1937b, p. 126-129); Barbieri (1937); Bode (1937); Campbell (1936, p. 297); Campbell and Campbell (1937); Free (1916); Wormington (1939, p. 41-43).

Artifacts have been found on the beaches of a former lake. No extinct animals have been reported. From a study of the history of the lake, Bode places the age as late Pleistocene, Antevs as late pluvial. The artifacts are deposited in the Desert Laboratory of the Southwest Museum at Twenty-Nine Palms, California.

Los Angeles.—Locality near Los Angeles, discovered, January, 1936; announced, Bowden and Lopatin, 1936. Principal literature: Bowden and Lopatin (1936); Hrdlička (1937c, p. 99-100).

Human bones, including part of skull, were found at a depth of 13 feet from the surface. In the same deposit about 1000 feet from the locality yielding the human bones and in the same stratum, proboscidean remains were found, identified as *Archidiskodon imperator* (Leidy). The deposits are stratified, consisting of black soil, 7 feet; peat, 2 feet; black clay, 2 feet; yellow clay, 1 foot; gravel containing bones, 2 feet. The collection is at the University of Southern California.

Potter Creek Cave.—Locality on Potter Creek, near Baird, Shasta County, explored, 1902-03; announced, Sinclair, 1904. Principal literature: Cope (1879; 1891); Howard (1936b, p. 407); Matthew and Gidley (1906); Merriam (1906, p. 223-225); Putnam (1906, p. 230-234); Sinclair (1904); Sinclair and Furlong (1904, p. 412-413).

Sinclair is of the opinion that the fauna of this cave is of "later Quaternary age." Among many pieces of splintered bone, two pieces found interbedded with the cave fauna represent, in the opinion of Putnam, Matthew, and Gidley, the work of man. The extinct vertebrate species listed by Sinclair (1904, p. 17-18) are the following: *Arctotherium simun* Cope, *Ursus* n. sp., *Felis* n. sp., *Canis indianensis* Leidy, *Taxidea* n. sp. (?), *Spilogale* n. sp., *Teonoma* n. sp., *Thomomys* n. sp., *Aplodontia major* n. subsp., *Platygonus* (?) sp., *Euceratherium collinum* n. gen. and sp., *Bison* sp., Camelid, *Megalonyx wheatleyi* (?) Cope, *Megalonyx jeffersonii* (?) (Desmarest), *Megalonyx* n. sp., *Megalonyx* sp., *Mastodon americanus* (Kerr), *Elephas primigenius* Blumenbach, *Equus occidentalis* Leidy, *Equus pacificus* Leidy. The collections are at the University of California.

Pinto Basin.—Locality in the northeastern part of Riverside County, discovered, 1935; announced, Campbell and Campbell, 1935. Principal literature: Amsden (1935a); Campbell and Campbell (1935); Campbell (1936, p. 296); Scharf (1935); Wormington (1939, p. 38-41).

Artifacts have been found in the site of former drainage and under conditions indicating a climate more moist than at present. Extinct animals, including horse and camel, have been obtained also. Actual association of the extinct animals and the artifacts, however, has not been established.

The collections are in the Desert Laboratory of the Southwest Museum at Twenty-Nine Palms, California.

Rancho La Brea.—Locality Rancho La Brea, Los Angeles, discovered, February, 1914; announced, Merriam, 1914. Principal literature: Boule (1923, p. 408); Hay (1927b, p. 182); Hrdlička (1918, p. 17-22); Merriam (1914); Stock (1930a, p. 28).

Many extinct vertebrates have been obtained from the asphalt pits of Rancho La Brea. In pit number 10, human bones were found at depth 6 to 9 feet. According to Merriam, the associated fauna is of later age than that of some other pits and is either early Recent or very late Pleistocene. The collections are largely at the Los Angeles Museum of History, Science, and Art and at the University of California.

Samwell Cave.—Locality on the east side of McCloud River about 16 miles above its mouth, Shasta County, discovered, 1903; announced, Furlong, 1904. Principal literature: Furlong (1904); Merriam (1906); Putnam (1906).

A piece of chipped lava was found in association with extinct animals. Furlong considers the chipped lava as probably included at the same time as the animal remains but considers the proof not conclusive.

Table Mountain.—Locality on Mormon Creek near Tuttletown, Toulumne County. Principal literature: Becker (1891, p. 189); Blake (1899); Hay (1920; 1927b, p. 226); Holmes (1899, p. 615-623; 1901; 1919, p. 62); Merriam (1936, p. 1315); Wright (1890, p. 502).

Merriam believes that many of the artifacts supposed to be found in the auriferous gravels had been moved from their original position in connection with hydraulic mining operations. A seemingly well authenticated discovery is that made by Clarence King who, according to Becker, discovered, in 1869, an artifact unmistakably in place in the gravel deposits under the lava cap of Table Mountain. Apparently nothing short of a restudy with extensive excavation will afford a satisfactory understanding of this locality.

COLORADO

Dent.—Locality near Dent, Weld County, discovered, 1932; announced, Figgins, 1933. Principal literature: Figgins (1933a); Howard (1935, p. 148); Roberts (1937b, p. 160); Strong (1935, p. 223); Wormington (1939, p. 13).

A large Folsom-like spear was found on November 5, 1932, associated with the skeleton of an elephant. A second artifact was found on July 7, 1933, also in association with elephant bones. Twelve elephants are said to be represented in the collections from this locality which is described as a terrace of South Platte River. The species is not fully determined but is probably of the *Parelephas columbi* group or possibly intermediate between *Parelephas columbi* (Falconer) and *Mammonteus primigenius* (Blumenbach). The collections are mostly in the Colorado Museum of Natural History.

Lindenmeier.—Locality 28 miles north of Fort Collins in Sec. 27, T. 12 N., R. 69 W., 6th Principal Meridian, discovered, 1934; recognized as Folsom, 1930; announced, Roberts, 1935. Principal literature: Kirk Bryan (1937a, p. 143-152); Bryan and Ray (1939); Coffin (1937); Figgins (1935c); Howard (1936b, p. 408; 1937a, p. 111); Renaud (1932a); Richards (1936, p. 370); Roberts (1935a; 1935b; 1936a; 1936b; 1937b, p. 158-160; 1938; 1939); Strong (1935, p. 223-224); Wormington (1939, p. 18-21).

Artifacts are found in a camp site at maximum depth of 14 or 15 feet below present land level. This was the first discovery of an occupational site of Folsom man. Bison remains found near the camp site probably represent a bison kill. The species, according to Gazin, is *Bison taylori* Hay and Cook. Bryan (1937a, p. 149) correlates the terrace containing the artifacts with the 25-foot terrace in the mountain section of Cache la Poudre River and with the 30-foot terrace of South Platte River. A proboscidean tusk has been found by Roberts but not in immediate association with the artifacts (personal communication). The collections are mostly at the Smithsonian Institution, Washington, D. C.

Soda Creek.—Locality on Soda Creek (long. 105°40′; lat. 39°35′), discovered, September, 1860; announced, Berthoud, 1866. Principal literature: Berthoud (1866, p. 342-345); Hrdlička (1907, p. 20).

Human skeletal remains were found in boulder deposits at a depth of 22 feet. No extinct species are reported. Geologic conditions are not adequately described, and the disposition of the collection is unknown.

Yuma County.—Localities on the uplands and stream divides in Yuma County, announced, Cook, 1931. Principal literature: Cook (1931a, p. 102-103); Figgins (1934; 1935b); Renaud (1932b).

Artifact and bones of elephant and two species of bison were found. Cook is of the opinion that some of the elephant bones and some bison bones show markings made by implements previous to fossilization. Of the two bison, one, according to Cook, is *Bison taylori* Hay and Cook. The other is a smaller species. The species of elephant is not given.

DELAWARE

Claymont.—Locality near Claymont, discovered, July, 1887. Literature: Cresson (1890).

Two artifacts were found in gravel in railway cut. No associated fossils were found.

Wilmington.—Locality near Wilmington. Literature: Cresson (1892).

Artifacts are reported to have been found in clays. No associated extinct animals were found.

FLORIDA

Flagler Beach.—Locality near Flagler Beach, discovered, 1931; announced, Connery, 1932. Literature: Connery (1932).

Artifacts are reported to have been found at a depth of about 2½ feet from the surface. It is said that one of the artifacts lay near or between

the jaws of an elephant. The level of the bones is below ground water level. The deposits consist of sandy layers with much organic material. The unconsolidated nature of the deposits would seem to create doubt as to the assurance of contemporaneity of the artifact and fossil. The disposition of the collection is unknown.

Lake Monroe.—Locality in bluff bordering Lake Monroe, discovered about 1852. Principal literature: Agassiz (1854); Hrdlička (1907, p. 19); Usher (1854).

Human skeletal remains are reported to have been found in fresh water marl by Pourtales. The depth, condition of occurrence, and disposition of the collection are unknown. No extinct vertebrates are reported from this locality.

Melbourne.—Three localities have been described near Melbourne as follows: 1½ miles southwest of Melbourne; 2 miles west of Indian River, on east bank of drainage canal; and one mile west of golf course on south bank of drainage canal. Discovered, 1923 and 1925; announced, Loomis, 1924, and Gidley and Loomis, 1926. Principal literature: Cooke (1926; 1928); Cooke and Mossom (1929, p. 218-220); Gidley (1926a; 1926b; 1926c; 1927; 1929a; 1929b; 1930; 1931); Gidley and Loomis (1926); Goddard (1926); Hay (1927b, p. 274); Howard (1935, p. 142); Hrdlička (1937c, p. 95-98); Leverett (1931); Loomis (1924; 1926); Romer (1933, p. 78); Simpson (1929).

The essential facts of the geologic section at Melbourne are as follows: At the base, a marine shell marl, the deepest formation reached in the excavation; above this, a nonmarine sand stratum containing vertebrate fossils and human remains; and an uppermost deposit, consisting largely of muck and loose sand. To the marine shell marl, which is widely distributed in Florida, the writer in 1912 applied the name Anastasia formation, the type locality being on Anastasia Island near St. Augustine, Florida. The nonmarine sand stratum contains vertebrate fossils and occurs widely on both the east and west coasts of Florida; Cooke and Mossom applied to it the name Melbourne bone bed, the type locality being at Melbourne. The overlying muck and sand deposits are local in occurrence and apparently conform to present topographic features. They are, however, a distinctive unit separated by erosional unconformity from the underlying Melbourne bone bed. For this unit the writer now proposes the name Van Valkenburg beds, the type locality being on Van Valkenburg Creek at Vero Beach, Florida.

The first artifact associated with extinct animals at Melbourne was found by Loomis in December, 1923, at a locality on the G. L. Singleton estate, 1½ miles southwest of the city. The fossils in immediate association with the artifact were *Parelephas columbi* (Falconer) and *Odocoileus sellardsiae* Hay. The bones and the artifacts were in the base of the sand stratum of the Melbourne formation. The artifacts and associated skeleton of *P. columbi* are in the museum of Amherst College. Additional excavations were made by Gidley and Loomis in 1925. Here at or near

the top of the Melbourne bone bed they found artifacts and charcoal in immediate association with bones of *Mylodon, Megalonyx,* and *Chlamytherium.*

The second locality is on the east bank of a drainage canal, 2 miles west of Indian River, near the club house of the Melbourne golf course. A crushed human skull and some other bones were found within a few inches of the top of the sand stratum of the Melbourne formation. Gidley (1929a, p. 493) is of the opinion that the skull belongs to the Melbourne bone bed. It is to be noted, however, that the skull lay essentially at the contact of the Melbourne formation with the overlying Van Valkenburg beds and hence may possibly belong to the latter formation. Additional excavations were made by Gidley in 1927-28. At that time an artifact was found near the middle of the Melbourne bone bed and numerous artifacts and some human skeletal remains at the contact of the Melbourne bone bed and the overlying Van Valkenburg beds.

The third locality is one mile west of the golf course on the south bank of a drainage canal. Artifacts and pieces of pottery were found at or near the contact of the Melbourne bone bed and the Van Valkenburg beds.

The vertebrate fossils obtained from the Melbourne formation at Melbourne, according to Gidley and Loomis, are very much the same as from that formation at Vero. A list of the vertebrate species has been given by Hay and by Simpson. Gidley is of the opinion that the fauna of this bed is Pleistocene (1929a, p. 493). Among extinct species of mammals from this locality identified by Loomis and by Gidley (Hay, 1927b, p. 273-274) are the following: *Elephas columbi, E. imperator?, Mastodon americanus, Canis dirus, Smilodon* sp., *Equus complicatus, E. leidyi, E. littoralis, Tapirus haysii, Bison latifrons?, Odocoileus sellardsiae, Platygonus* sp., *Camelops?* sp., *Megalonyx jeffersonii?, Mylodon* sp., *Chlamytherium septentrionalis, Glyptodon* sp., *Dasypus* sp. The collections are at the U. S. National Museum, Washington, D. C., and at Amherst College, Amherst, Massachusetts.

New Smyrna.—Locality at New Smyrna, discovered, 1929; announced, Gidley, 1929. Literature: Gidley (1929b, p. 20).

Gidley found artifacts in "undisturbed natural association" with bones of extinct animals. No additional information on the locality seems to have been published.

Osprey.—Four localities for human remains have been reported near Osprey, Manatee County, as follows: Osprey, 1871; North Osprey, 1872; South Osprey, about 1888; and Hanson Landing, 1886. Announced, Heilprin, 1887. Principal literature: Agassiz (1854); Heilprin (1887); Hrdlička (1907, p. 53-55); Leidy (1889, p. 10-12); Vaughan (1907); Webb (1907).

Human skeletal remains were found at the surface or at shallow depth. No extinct species were obtained in immediate association with the human

remains. Vaughan is of the opinion that the deposits are post-glacial. The collections are in the National Museum, Peabody Museum, and Army Medical Museum.

Palma Sola.—Locality on beach at Palma Sola. Principal literature: Hay (1923, p. 379).

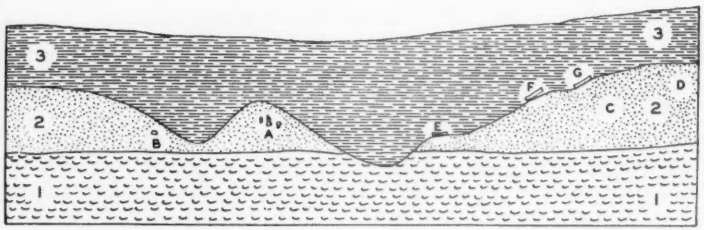

FIGURE 1.—*Sketch to show succession of strata at Vero, Florida*

(1) Anastasia formation; (2) Melbourne bone bed; (3) Van Valkenburg beds; (A) Human foot bones and parts of pelvis and bone implements; (B) Spall; (C) Fossil turtle; (D) Bone implements and foot bone of horse; (E, F, G) Human bones. (From Florida State Geol. Survey, 8th Ann. Rept., Figure 6, 1916.) Scale, horizontal and vertical: 1 inch = 7 feet.

A fossilized human skull has been found. Various fossils are washed up on the beach, but their association with the skull is not established.

Vero.—Locality in the valley of Van Valkenburg Creek one-half mile north of Vero Beach, discovered, October, 1915; announced, Sellards, 1916. Principal literature: Balch (1917, p. 481-482); Berry (1917); Boule (1923, p. 409-411); Chamberlin (1917a; 1917b); Cooke (1926; 1928); Cooke and Mossom (1929, p. 220-224); Gidley (1930); Hay (1917a; 1917b; 1917c; 1918a; 1918b; 1918c; 1919a, p. 108-109; 1923; 1926; 1927a; 1927b, p. 275; 1928c); Holmes (1918a; 1918b); Howard (1935, p. 140-142); Hrdlička (1917; 1918, p. 23-65; 1919; 1937c, p. 95); Keith (1929, p. 467-468); Leverett (1931); MacCurdy (1917a; 1917b); Merriam (1935; 1936, p. 1316); Nelson (1918b); Romer (1933, p. 78); Sellards (1916a; 1916b; 1916c; 1917a; 1917b; 1917c; 1917d; 1918; 1919; 1937); Simpson (1929; 1930a); Shufeldt (1917); Sterns (1918; 1919); Vaughan (1917); Wickham (1919); Wieland (1918); Wilder (1924, p. 288-289).

The geologic section at Vero has been fully described in earlier publications, but for convenience of reference a graphic representation is given in Figure 1. As at Melbourne, there are three distinct geologic units in the section. At the bottom is the Anastasia marl, No. 1 of the sketch, a marine formation in which neither vertebrate fossils nor human relics have been found. Resting on the marl is a nonmarine sand stratum, No. 2, to which the name Melbourne bone bed has been applied by Cooke and Mossom. Overlying the Melbourne bone bed, separated by an erosional unconformity, is a deposit of sand and muck, No. 3, to which the writer now applies the name Van Valkenburg beds, this being the type locality.

The essential facts are that the Melbourne bone bed and the Van Valkenburg beds at this place both contain vertebrate fossils and human

remains. Failure on the part of several writers to distinguish between these two deposits has led to confusion in the literature. Thus Holmes (1918b) has not recorded the fact that the pottery described by him came only from stratum No. 3, the Van Valkenburg beds. Likewise,

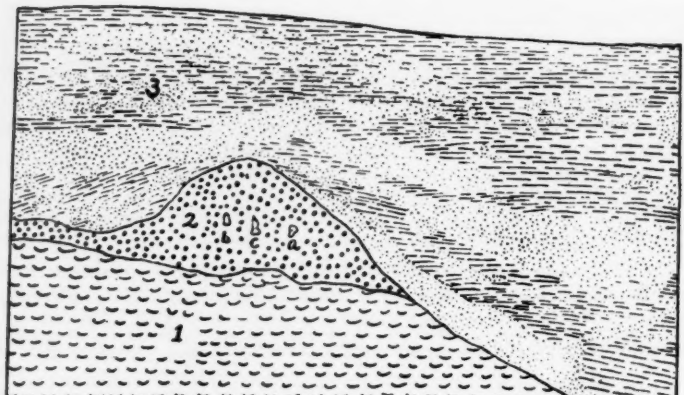

FIGURE 2.—*Detail of a part of the section from Figure 1*

(a, b) Human foot bones; (c) Scapula of deer and bone implements. (From Florida State Geol. Survey, 8th Ann. Rept., Figure 5, 1916.) Scale, vertical and horizontal: 1 inch = 2.5 feet.

MacCurdy (1917b) has assumed, supported to some extent by Berry, that no appreciable interval of time separates stratum No. 2, the Melbourne bone bed, from the Van Valkenburg beds. With this erroneous assumption he arrives at the conclusion that all the human remains and artifacts found at Vero are relatively recent in age and that this great fauna persisted in Florida into Recent time. The contention of Hrdlička that the human skeletal remains and artifacts in these stratified deposits represent relatively modern burial by human agency is too much without reason or merit to justify discussion.

Human foot bones and parts of the pelvis, flint chips or spalls, and bone implements were found in the Melbourne formation (Figure 1). To show more definitely the place of the human foot bones in the section, the writer made at the time the excavations were in progress the more detailed sketch shown in Figure 2. This part of the section is shown by photograph on Plate 1. The erosional contact between the Van Valkenburg beds and the Melbourne bone bed is very definite, as may be seen in the photograph.

Extinct species of mammals collected in place by the writer from the Melbourne bone bed at this locality are the following: *Megalonyx jeffersonii* (Desmarest), *Chlamytherium septentrionalis* (Leidy), *Dasypus* sp., *Equus leidyi* Hay, *Equus complicatus* Leidy, *Tapirus veroensis* Sellards, *Camelops?* sp., *Mastodon americanus* (Kerr), *Parelephas columbi* (Falconer), *Aenocyon ayersi* (Sellards), and *Smilodon* (*Trurifelis*) *floridanus* (Leidy). For identification of the large fauna and flora found in the Melbourne and Van Valkenburg formations, the reader may consult the extensive literature, especially papers by Berry, Hay, Sellards, Simpson, Shufeldt, and Wickham. The collections obtained at Vero are in the Museum of the Florida State Geological Survey, Tallahassee, Florida.

Winter Beach.—Locality a drainage ditch just east of Florida State highway No. 4 about 3 miles north of the Vero locality and approximately midway between the towns of Gifford and Winter Beach, discovered 1936.

Dr. C. R. Stauffer reports that in 1936 and 1937 Mr. P. D. McKellar, of Jackson, Minnesota, obtained bones of the ground sloth, camel, mastodon, and other animals from the Melbourne bone bed. On many of the bones obtained by Mr. McKellar, Dr. Stauffer found what he believes to be marks of flint knives and bruises of stone hammers made in breaking the bones. The marks were evidently made on fresh bones, and the breaks were also those of fresh bones and not the fracture of heavily mineralized specimens. One or two bones, Dr. Stauffer states, appear to have been used by man for some temporary purpose (letter of July 8, 1939). The collections are in the University of Minnesota and in a museum at the courthouse in Jackson, Minnesota. Dr. A. E. Jenks, who also visited this locality in 1937, believes that the bones are man marked (letter of July 10, 1939). Dr. Stauffer has kindly sent some of the bones to the writer. The markings on proboscidean and other bones appear to have been made by flint knives in cutting slices of meat from the bones.

IDAHO

Nampa.—Locality at Nampa, discovered, 1889. Literature: Holmes (1919, p. 70).

An image, taken from a boring, is considered by Holmes as having no authenticated evidence of antiquity.

ILLINOIS

Rock Bluff.—Locality on Illinois River at Rock Bluff near crossing of 40th Parallel, discovered, June, 1866. Principal literature: Hrdlička (1907, p. 28-32); Kollmann (1884); Schmidt (1872, p. 237-244).

Human skeletal remains found in a crevice in limestone imbedded in "clay, sand and broken stone" at a depth of "several feet." No associated fossils were found. The collection is in the National Museum.

Walkerville.—Locality near Walkerville, Green County, discovered, May, 1879; announced, McAdams, 1881. Literature: McAdams (1881).

A stone ax is reported to have been found at the base of the loess deposits at a depth of 72 feet.

INDIANA

Cromwell.—Locality near Cromwell, announced, Burmaster, 1932. Literature: Burmaster (1932); Harrington (1933, p. 180).

A mastodon skeleton was found resting on clay and protruding upwards through overlying peat. An artifact was found on the clay within 20 feet or less from the mastodon. Another artifact was found in the peat deposit. Charcoal was found on the clay and under the skeleton. Collections in Buffalo Museum of Science, Buffalo, New York.

Medora.—Locality on East Fork of White River, near Medora, Jackson County, discovered, 1886; announced, Cresson, 1890. Literature: Cresson (1890).

An artifact was found in gravel 8 feet below the surface and about 50 feet above water level in the river. No fossils are reported.

IOWA

Muscatine.—Locality near Muscatine, discovered about 1891; announced, Witter, 1892. Principal literature: Shimek (1917, p. 98); Witter (1892).

Two artifacts and parts of tooth of an elephant found in loess deposits at depth of 12 and 25 feet. The species of elephant is not given. The disposition of the collection is unknown.

Sioux City.—Locality 3 miles east of Sioux City, discovered about 1869; announced, Aughey, 1876. Principal literature: Aughey (1876, p. 254-255).

An artifact was found in loess deposits in railway cut 15 feet below the surface. No associated extinct animals are reported. The location of the artifact is unknown.

KANSAS

Lansing.—Locality on the Concannon farm on the right bank of Missouri River, 5 or 6 miles southeast of Leavenworth, discovered, February, 1902; announced, Williston, 1902. Principal literature: Boule (1923, p. 407); Calvin (1902); Chamberlin (1902); Holmes (1902a; 1919, p. 71); Hrdlička (1907, p. 47-53); Keith (1929, p. 468-469); Salisbury (1902); Shimek (1903); Todd (1903); Upham (1902a; 1902b; 1902c); Williston (1902b; 1903; 1905b); Winchell (1902; 1903; 1917, p. 134).

Human remains were found in loess at depth 20 feet. T. C. Chamberlin, Salisbury, and Calvin consider it possible that the loess in which the skeleton rests is a secondary deposit. Winchell, Williston, and Upham regard the deposition as original. The skull is in the Smithsonian Institution, Washington, D. C.; the lower jaws and some other skeletal material are in the Museum of Vertebrate Paleontology of the University of Kansas. This locality has recently been revisited by Smith, Hib-

bard, and Eiseley and may be restudied in the near future (letter of H. T. U. Smith, June 23, 1939).

Russell Springs.—Locality on Twelve Mile Creek, a small tributary to Smoky Hill River, about 12 miles east of Russell Springs, Logan County, discovered, 1895; announced, Williston, 1897. Principal literature: Boule (1923, p. 400-401); Lucas (1899); McClung (1908); Martin (1902); Renaud (1928, p. 31); Romer (1933, p. 79); Schultz and Eiseley (1935, p. 312); Stewart (1897); Williston (1897; 1898; 1902a; 1905a).

In the summer of 1895, H. T. Martin and T. R. Overton, of the University of Kansas, found some bone fragments that had been washed from blue clay. According to Martin, the clay stratum rested on chalk at a level 10 or 12 feet above the bed of the small stream. A quarry was opened which proved to contain an unusual cache of bison remains. Parts of seven or eight bison skeletons were obtained, from which one skeleton was subsequently mounted in the University of Kansas Museum. This bison, originally referred to *Bison antiquus* Leidy, was later described by Lucas as *Bison occidentalis* Lucas. When these skeletons were removed a worked flint was found under one of them 15 or 18 feet from the margin of the quarry and at a vertical depth of about 20 feet. Mr. Martin gives details of the discovery as follows (letter of January 15, 1918):

"In reply to your letter in regard to the finding of the arrowhead with the skeleton of *Bison occidentalis* Lucas collected by the writer in the Pleistocene of western Kansas and now mounted in our Museum, I beg to state that the work of cleaning and removing the skeleton was continuous. After we reached within a few inches of the bone layer, the surface was cleaned off perfectly level for a space of fifteen by twenty to twenty-five feet. The skeleton lay with the head pointing nearly east, and the skull separated about three feet to the southwest, so what when I commenced removing the parts after pasting, the scapula came in the second block to be removed. These sections separated from the matrix beneath freely, so that when the scapula was removed, it left a nearly perfect impression in the bluish marly matrix, leaving the arrowhead plainly in view firmly embedded in the hard matrix. When this was removed, it too left a perfect mold in the firm clay, so you can see that accidental intrusion in any way imaginable was absolutely impossible.

"The arrowhead was embedded more deeply at its base, while the point was pressed firmly against the shoulder blade. The skeleton lay on its right side and the arrowhead underneath the right scapula. These positive facts should, and I hope will, convince the most sceptical that any theory they may advance as to the possibility of accidental intrusion of the arrowhead subsequently to the deposition of the skeleton is positively precluded by the firm impression left in the solid matrix beneath the shoulder blade. All bones of the skeleton were cleaned off and removed by the writer."

Having collected in Kansas with Mr. Martin and having been otherwise associated with him for several years, the writer has personal knowledge of his exceptionally painstaking methods of collecting and removing vertebrate fossils. His statement of the manner of occurrence of the artifact under the scapula of this bison will appeal to all who knew him as thoroughly trustworthy, affording a reliable record of the presence of a worked flint under the skeleton of *Bison occidentalis* Lucas. Martin's

judgment as to the contemporaneity of the flint and the bison has been expressed by him as follows:

"It must have been within the body of the animal at the time of death or have been lying on the surface beneath its body."

Williston (1902a, p. 315) reports that he obtained, nearby, two extinct mammals, *Mammonteus* (*Elephas*) *primigenius* (Blumenbach) and *Platygonius compressus* LeConte, from the plains marl. This marl overlies the blue clay stratum which contained the bison bones at this locality.

Smith County.—Locality on a stream terrace, Smith County, discovered, 1937; announced, Smith, 1938. Principal literature: Smith (1938); Eiseley (1939a).

Artifacts were found in stream terrace. Bison, probably the existing species, and invertebrate fossils were present. The collections are at the University of Kansas.

LOUISIANA

Avery Island.—Locality at a salt mine on Avery Island, discovered, 1890; announced, Joor, 1895.

Pottery and a basket were found in a muck bed at a depth of 10 or 12 feet (Joor, 1895). Underlying the muck is blue clay containing extinct animal remains including mastodon, horse, and sloth. No human materials were found in association with the extinct animals. The collections were placed in Tulane University.

New Orleans.—Locality in excavation for gas tank in the city of New Orleans, discovered, 1844. Principal literature: Drake (1850, p. 76); Hrdlička (1907, p. 15); Lyell (1863, p. 43-44); Nott and Gliddon (1854, p. 272); Usher (1854, p. 338).

Human bones are reported in an alluvial deposit at a depth of 16 feet. No associated vertebrate fossils were found. The disposition of the collection is not known.

MASSACHUSETTS

Worcester County.—Locality in Northborough, Worcester County, discovered, 1884. Principal literature: Putnam (1885).

Parts of skull and teeth of a mastodon were found at the bottom of peat deposits. About 18 feet from the mastodon skull occurred a human skull and jaws which, likewise, rested on the underlying deposits at the base of the peat deposits.

MINNESOTA

Browns Valley.—Locality in a gravel pit in Browns Valley near Fertile, discovered, July, 1934; announced, Jenks, 1934. Principal literature: Jenks (1934); Worthington (1939, p. 27-28).

Artifacts and a human skeleton were found, representing a burial. Jenks regards three of the artifacts as of the Folsom culture. Wormington regards the artifacts as of the Yuma culture. The collections are mostly with Wm. H. Jensen, Browns Valley, who discovered the site.

Lake Itasca.—Locality at Lake Itasca, discovered, 1937.

Exploration by Jenks and Eddy in 1937 yielded bones of *Bison antiquus* and a few flaked knives at a depth of 8 feet under marl and peat deposits (Eddy, letter of July 21, 1939).

Little Falls.—Locality on Mississippi River at Little Falls, discovered, 1879; announced, Babbitt, 1883. Principal literature: Babbitt (1883; 1884); Haynes (1890); Holmes (1893c; 1919, p. 84); Upham (1884; 1888; 1902a); Wright (1890, p. 509).

Artifacts were found in a Mississippi River terrace. The depth of the artifacts below the top of the terrace is given as "12 or 15 feet." Subsequently, Holmes trenched the face of the terrace and expressed the opinion that the artifacts found by Miss Babbitt were a part of the superficial deposits. Apparently no additional investigations have been made.

No extinct species of animals are reported. The collections obtained by Miss Babbitt are in the Peabody Museum of Harvard University.

Pelican Rapids.—Locality on Minnesota State highway No. 30, about 3 miles north of Pelican Rapids, Ottertail County, discovered, 1931; announced, Jenks, 1932. Principal literature: Antevs (1935, p. 305; 1937d; 1938a); Kirk Bryan (1935); Bryan and MacClintock (1938); Hrdlička (1937c, p. 101-104); Jenks (1932a; 1933; 1935, p. 5-7; 1936; 1938); Kay and Leighton (1938); Sardeson (1938); Thiel (1936); Wormington (1939, p. 54-57).

A human skeleton and some artifacts were found in lake deposits at a depth of 12 feet. In the opinion of Jenks, Bryan, Kay, Leighton, and MacClintock, the human materials are of the age of the lake deposits; Antevs, Sardeson, and Hrdlička believe the human remains to be of later age than these deposits. No extinct animals were found. The collections obtained are at the University of Minnesota.

Sauk Valley.—Locality in gravel pit near Lake Guerney in West Union Township, Todd County, discovered, June, 1935; announced, Bryan, Retzek, and McCann, 1938. Principal literature: Bryan, Retzek, and McCann (1938); Jenks and Wilford (1938); Wormington (1939, p. 58-59).

Human skeletal remains were found in a gravel deposit at a depth of from 2 to 4 feet. No associated fossils reported. The collection is in the possession of Rev. Henry Retzek.

Valley of Saint Croix River.—Three or more localities in the Valley of St. Croix River in Interstate Park, discovered, 1934; announced, Eddy and Jenks, 1935. Principal literature: Eddy and Jenks (1935).

At the original locality kitchen midden deposits were found underneath peat bog deposits. The midden deposits are said to contain artifacts and many bones of an extinct bison. Eddy (letter of June 28, 1939) reports that

"all of these sites consisted of large numbers of remains of *Bison antiquus* Leidy, caribou, and other mammals, many of which bore knife marks and some of which had been fashioned into implements."

One wooden artifact was also discovered. These finds were all in marl, maximum depth 22 feet, deposited in former lakes which, according to

pollen profiles and other evidence, indicated an early post-glacial date. The collections are at the University of Minnesota. (Jenks, letter of July 22, 1939.)

MISSISSIPPI

Natchez.—Locality near Natchez, discovered, 1846; announced, Dickeson, 1846. Principal literature: Dickeson (1846); Howard (1936b, p. 394; 1936g, p. 1327); Hrdlička (1907, p. 16-19); Keith (1929, p. 465-467); Leidy (1889, p. 9); Lyell (1849; 1863, p. 200-205); Schmidt (1872); Usher (1854, p. 349); Winchell (1917, p. 133).

Lyell, who examined the pelvic bone of man and other fossils, states that the human bone "appeared to be quite in the same state of preservation and was of the same black color as the other fossils." Leidy also observed that the degree of fossilization was exactly the same as that of the bones of extinct mammals which were found with it and that the bone differs in no respect from that of the corresponding recent bone of man. The fossils reported to occur with the human bone (Leidy, 1889) are: *Mastodon americanus* (Kerr), *Megalonyx jeffersonii* (Desmarest), *M. dissimilis* Leidy, *Ereptodon priscus* Leidy, *Mylodon harlani* Owen, *Equus major* (Leidy), and *Bison latifrons* (Harlan). The horizon from which the bones were thought to have been derived is a clay stratum at a depth approximately 30 feet from the surface. The top of the terrace from which the fossils were obtained is about 200 feet above the present river level. The collection is in the Academy of Natural Sciences of Philadelphia (Howard, 1936g).

MISSOURI

Benton County.—Locality on Pomme de Terre River in Benton County, discovered, 1839; announced, Koch, 1839. Principal literature: Dana (1875, p. 337); Howard (1935, p. 143); Koch (1839a; 1843; 1857, p. 63).

Koch reports mastodon bones found at a depth of 20 feet with which were associated "several stone arrowheads." One of the artifacts was found underneath the femur of the mastodon "so that it could not have been brought thither after the deposit of the bones." The disposition of the collection is unknown.

Gasconade County.—Locality a spring in the valley of Bourbeuse River in Gasconade County, discovered, October, 1838; announced, Koch, January, 1839. Principal literature: Dana (1875, p. 338-339); Howard (1935, p. 143; 1936b, p. 394); Koch (1839a; 1839b; 1857); Harrington (1933, p. 177); McGee (1888).

Koch reports having found remains of a mastodon skeleton at a depth of about 8 or 9 feet in alluvial deposits. With the bones was evidence of fire as well as "several arrowheads, a stone spearhead and some stone axes." Some of the mastodon bones, according to Koch, had been burned. So far as the writer has found record, this was the first reported find of man's relics in association with extinct animals in North America. These

and other collections made by Koch were kept for a time in a museum in St. Louis. According to John Francis McDermott (letter of July 31, 1939), Koch sold his museum in 1841 and upon leaving St. Louis took his collections with him, some of which were disposed of in Europe. The whereabouts of the mastodon remains and associated artifacts is unknown.

Kimmswick.—Locality 25 miles west of St. Louis. Literature: Holmes (1902b, p. 108-129).

Remains of mastodon and elephant are found. Some artifacts are reported, but proof of actual association, according to Holmes, is lacking. Some fossils from this locality are in the U. S. National Museum (Gazin, letter of September 27, 1939).

NEBRASKA

Agate.—Locality one-half mile east of Agate.

At this locality, according to Cook, elephant, extinct deer, and undetermined bison were found in and under a peat bed in association with artifacts (letter of August 28, 1939).

Angus.—Locality near Angus, Nuckolls County, discovered, August, 1931; announced, Figgins, 1931. Principal literature: Bell and Van Royen (1934a, p. 58-60); Figgins (1931); Harrington (1933, p. 180); Strong (1932a, p. 152; 1932b; 1935, p. 221); Wormington (1939, p. 11-13).

An artifact of the Folsom culture is reported to have been found in association with the skeleton of an elephant. The formation containing the fossil elephant and artifact consists of stratified deposits of sand and gravel, with thinner layers of silt, clay, and marl, overlain by wind-blown sand and prairie loess to a depth of 16 feet. The elephant has been described by Osborn as *Archidiskodon meridionalis nebrascensis* n. var. The collection is in the Colorado Museum of Natural History.

Bridgeport.—Locality Bridgeport near Dalton, Morrill County. Principal literature: Renaud (1934, p. 12-19); Schultz (manuscript).

Artifacts are found in association with *Castoroides ohioensis* Foster and *Bison antiquus taylori* (C. B. Schultz, personal communication). The collections are in the University of Nebraska State Museum.

Crawford.—Locality in headwater drainage of White River, near Crawford, discovered, 1935; announced, MacClintock and others, 1936. Principal literature: MacClintock, Barbour, Schultz, and Lugn (1936).

Artifacts and fire pits have been found in the valley of Sand Creek at varying depths up to about 25 feet. The artifacts and fire pits underlie and antedate varved deposits. Schultz (letter of June 24, 1939) states that *Bison antiquus taylori* has been found in the valley of Sand Creek. The collections are in the University of Nebraska State Museum.

Cumro.—Locality in South Loup Valley, Custer County, about 7 miles southwest of Cumro (T.13 N.; R.19 W.; Sec. 35), discovered, 1929; announced, Schultz, 1932. Principal literature: Antevs (1935, p. 304); Bell and Van Royen (1934a, p. 53-56); Schultz (1932, p. 271-273); Strong (1932b, p. 2; 1935, p. 220).

An artifact was found in association with a bison skeleton in loess deposits at depth of 16 feet. Schultz is of the opinion that the loess is of late Wisconsin age (letter of June 24, 1939). The bison skull was wanting, but the species was thought to be *Bison occidentalis* Lucas, or a closely related species. The collections are in the University of Nebraska State Museum.

Dalton.—Locality on East Fork of Greenwood Creek, about 10 miles northwest of Dalton, discovered, September, 1932; announced, Bell and Van Royen, 1933. Principal literature: Bell and Van Royen (1933; 1934a, p. 51, 63-69; 1934b, p. 303); Strong (1935, p. 222-223).

Artifacts were found in terrace deposits at a depth of 7½ feet. The height of the terrace is 14 to 20 feet above stream level. No extinct fossils are reported in immediate association with the artifacts. The collections are in the University of Nebraska, Department of Anthropology.

Gilder's Mound.—Locality 3 miles north of Florence, Douglass County, discovered, October, 1906; announced, Barbour and Ward, 1906. Principal literature: Barbour (1907a; 1907b; 1907c; 1907d; 1907e); Barbour and Schultz (1936b); Barbour and Ward (1906a; 1906b); Blackman (1907); Boule (1923, p. 407); Gilder (1907a; 1907b); Hrdlička (1907, p. 66-98); Keith (1929, p. 469-471); Osborn (1907a, p. 372-373); Shimek (1908); Winchell (1917, p. 135).

Human remains were found to a depth of 12 feet. No associated extinct animals were obtained. The collections are in the University of Nebraska State Museum.

Grand Island.—Locality on south bank of Platte River, 8 miles southwest of Grand Island, Hall County, discovered, 1923 and 1931; announced, Meserve and Barbour, 1932. Principal literature: Barbour and Schultz (1932a); Bell and Van Royen (1934a, p. 56-58); Meserve and Barbour (1932); Schultz (1932, p. 273-275); Strong (1932b; 1935, p. 221).

Two artifacts have been found in association with a bison, originally identified as *Bison occidentalis* Lucas, now regarded as *Bison antiquus taylori* (Schultz, letter of June 24, 1939). The fossils are found in a dark silt stratum. The depth of the bone bed is about 4 feet. The collections are in the University of Nebraska State Museum.

Omaha.—Locality in a railway cut 2½ miles southeast of Omaha, discovered, 1872; announced, Aughey, 1876. Principal literature: Aughey (1876, p. 254); Hay (1918a; 1929a, p. 95).

Aughey obtained a large flint arrowhead from the loess deposits at a depth of 20 feet. The artifact was 13 inches below and a little to one side of the lumbar vertebra of a proboscidean. The present location of the fossil and artifact is unknown.

Scottsbluff.—Locality in north bank of Spring Creek near Signal Butte, Scotts Bluff County (S.W. ¼, Sec. 11, T. 21 N., R. 57 W.), discovered, August 4, 1932; announced, Barbour and Schultz, 1932. Principal literature: Barbour and Schultz (1932b; 1936a, p. 434-442); Bell (1932); Bell and Van Royen (1934a, p. 60-62); Figgins (1934); Howard (1935, p. 147-148); Lugn (1934, p. 353; 1935, p. 183-188); Romer (1933); Schultz (1934); Schultz and Eiseley (1935; 1936a); Strong (1935, p. 221).

Eight artifacts were found in immediate association with *Bison taylori* Hay and Cook (Barbour and Schultz, 1936a, p. 434). The bones and artifacts occur in stream deposits. The overlying material, 12 feet or more in thickness, is said to be wind blown (Schultz and Eiseley, 1935, p. 307). The collections are in the University of Nebraska State Museum.

Signal Butte.—Locality on a mesa near Scottsbluff, discovered, 1931; announced, Strong, 1932. Principal literature: Amsden (1937, p. 94); Strong (1932a, p. 155; 1933; 1935); Wormington (1939, p. 32-34).

Amsden considers the culture stage of the lowest level at this locality comparable to that of Lake Mohave. Strong is of the opinion that this site contains material related to but later than the Folsom horizon at the Lindenmeier site. No extinct animals have been obtained. The collections are in the Smithsonian Institution, Washington, D. C.

Snake Creek site.—Locality in ancient stream bed near the head springs of Snake Creek, discovered, 1908; announced, Osborn, 1922. Principal literature: Boule (1928); Cook (1927b, p. 114-116); Gregory (1927); Gregory and Hellman (1923a; 1923b); Keith (1929, p. 474); Nelson (1928); Osborn (1922a; 1922b; 1927); Renaud (1928, p. 27-31); Woodward (1922).

A fossil molar tooth found in Pliocene deposits was described by Osborn as a new genus, *Hesperopithecus,* representing an ape or man. On the basis of additional material subsequently obtained, Gregory concluded that the tooth was from an extinct peccary. Many bone fragments were found in the same formation, but none of these, in the opinion of Nelson, were shaped by man. The collections are in the American Museum of Natural History.

NEVADA

Gypsum Cave.—Locality in the foothills of Frenchman Mountains about 16 miles east of Las Vegas, discovered, 1930; announced, Harrington, 1930. Principal literature: Amsden (1931); Antevs (1935, p. 309); Harrington (1930; 1933; 1934c); Howard (1935, p. 146; 1936b, p. 406); Romer (1933, p. 81); Stock (1931); Wormington (1939, p. 35-38).

Artifacts were found in association with sloth (*Nothrotherium shastense* Sinclair), camel (*Camelops* sp. and *Tenupalama* sp.), and horse (Harrington, letter of August 21, 1939). The collections are in the Southwest Museum and California Institute of Technology.

Lake Lahontan.—Locality on Walker River in the southern part of Lake Lahontan basin, discovered, October 6, 1882; announced, Russell, 1885. Principal literature: Antevs (1935, p. 304); Gilbert (1889); Harrington (1933, p. 178); Hay (1929a, p. 95);

Holmes (1919, p. 68); McGee (1887; 1888, p. 23; 1889b); Powell (1893, p. 324-325); Russell (1885, p. 246-247); Wright (1890, p. 558).

McGee (1889b, p. 304) states that the obsidian implement found by him was projecting point outward from the later clay deposits of Lake Lahontan. It was found in the vertical bluff at a depth of 25 feet from the surface. The fossils of this later Pleistocene lake epoch are listed by Hay as elephant, horse, bison, and camel.

Las Vegas.—Localities in the drainage area of Las Vegas River about 10 miles north-northwest of Las Vegas, discovered, 1933; announced, Simpson, 1933. Principal literature: Simpson (1933); Harrington (1934a).

Simpson reports "highly suggestive if not absolutely conclusive" evidence of existence of man with the fauna of Pleistocene type. Pieces of charcoal and a flake were found with the following fossils: *Thomomys? perpallidus, Equus pacificus* Leidy, *Equus* sp., *Camelops hesternus* (Leidy), *Odocoileus* sp., and *Bison* sp. Later Harrington found in a nearby locality additional charcoal inclusions; also split and burnt animal bones and one elephant molar, probably *Parelephas columbi* (Falconer). The maximum depth of the charcoal in the deposits is 14 feet. The collections are in the American Museum of Natural History, New York, Southwest Museum, Los Angeles, and California Institute of Technology, Pasadena, California.

Smith Creek Cave.—Locality in a cave near Baker, discovered, 1933; announced, Harrington, 1934. Principal literature: Harrington (1934b).

The cave deposits at this place contain charcoal, split and burned bones, presumably indicating human agency. The associated fossils are camel (*Camelops*), horse (two species), and other undetermined bones (Harrington, 1934b, p. 306; and letter of August 21, 1939). The collections are in the Southwest Museum and California Institute of Technology.

NEW JERSEY

Trenton.—Locality in gravel deposits on bluff of Delaware River, 2 miles south of Trenton, discovered, September, 1872; announced, Abbott, 1872. Principal literature: Abbott (1872; 1873; 1877; 1881, p. 471-551; 1883; 1889); Balch (1917, p. 474-477); Boule (1923, p. 402); Cresson (1892); Goddard (1927, p. 264); Hay (1919b; 1929a, p. 95); Haynes (1883); Hollick (1898); Holmes (1893a; 1898; 1919, p. 76); Howard (1936b, p. 394); Hrdlička (1907, p. 35-47); Keith (1929, p. 461-465); Knapp (1898); Kümmel (1898); Lewis (1880; 1881); McGee (1889a); Mercer (1898); Powell (1893); Putnam (1898); Richards (1939); Russell (1899); Salisbury (1898); Shaler (1880; 1889; 1893); Smith (1910); Spier (1916; 1918); Volk (1911); Wilder (1924, p. 286-288); Wilson (1898); Wissler (1916, p. 236); G. F. Wright (1883; 1888a, p. 427; 1890, p. 509; 1892, p. 242-249; 1893, p. 29-32; 1898; 1911).

Artifacts have been reported at three levels. The uppermost level is in the surface soil; the second level is in yellow sand or sandy clay about 2 feet thick. Underneath the yellow sand is a gravel deposit known as the Trenton gravel. The gravel deposits are said by Abbott, Volk, and others to contain artifacts.

Among fossils reported from the Trenton gravel is a fragment of a human mandible found at a depth of 16 feet, also a parietal bone and femur. Mastodon and bison are reported in these deposits (Abbott, 1881, p. 482). The first artifact was found by Abbott in September, 1872, in the gravel at a depth of 16 feet (Abbott, 1873, p. 206). In a recent paper Richards reports that excavation carried on at this locality during the past three years has failed to yield artifacts from the Trenton gravel. The excavations in the Trenton gravel, however, were not extensive (Richards, letter of July 23, 1939). The artifacts from the yellow sand, Richards concludes, are of no great antiquity. Much of the material is in the Peabody Museum, Harvard University; the American Museum of Natural History; the University of California; and the New Jersey State Museum.

NEW MEXICO

Burnet Cave.—Locality about 26 miles west of Carlsbad (approximately 50 miles by road) on south fork of Rocky Arroyo on eastern side of Guadalupe Mountains (Sec. 35, R. 21 E., T. 22 S.), Eddy County, discovered, 1930; announced, Howard, 1930. Principal literature: Howard (1930; 1931; 1932; 1933, p. 524; 1935, p. 62-79; 1936b, p. 406; 1936f; 1936g, p. 1327-1329; 1937a, p. 112); Howard and Antevs (1934); Merriam (1936, p. 1316); Roberts (1937b, p. 157-158); Schultz and Howard (1936); Woodward (1935, p. 406); Wormington (1939, p. 15).

In Burnet Cave, a Folsom-like point was found at approximately 5½ feet, hearths at varying depths, and animal bones to a maximum depth of 8½ feet. Among extinct animals in the cave deposits were camel, horse, musk ox, bison, and cave bear. Schultz (letter of June 24, 1939) lists the following extinct species from this cave: *Arctodus* sp., *Equus excelsus, Equus tau, Camelops* sp., *Rangifer? fricki, Tetrameryx onusrosagris, Euceratherium collinum morrisi, Preptoceras sinclairi neomexicana,* and *Bison antiquus taylori.* The collections are in the University of Pennsylvania Museum, the Academy of Natural Science of Philadelphia, and the University of Nebraska State Museum.

Cimarron.—Locality on south bank of Cimarron River 8 miles east of Folsom, discovered, January, 1935; announced, Figgins, 1935. Principal literature: Figgins (1935a); Hrdlička (1937c, p. 98-99); Hooton (1937); Roberts (1937a); Shapiro (1937); Woodbury (1937).

A human skull and parts of a skeleton were found in stream deposits 13½ feet below the surface. The geology seems not to have been fully investigated. The human remains were described by Figgins (1935a) as a new species, *Homo novus mundus.* Roberts and others who have examined the skull consider it to represent *Homo sapiens* Linnaeus. No associated vertebrate fossils have been reported. The collection is in possession of J. D. Figgins.

Clovis.—Several localities near Clovis in Blackwater Draw (T. 1 S., R. 34 E. and R. 36 E.), discovered, 1932; announced, Howard, 1933. Principal literature: Antevs (1935, p. 309; 1936b); Frank Bryan (1938); Chaney (1935); Cotter (1937a); Howard

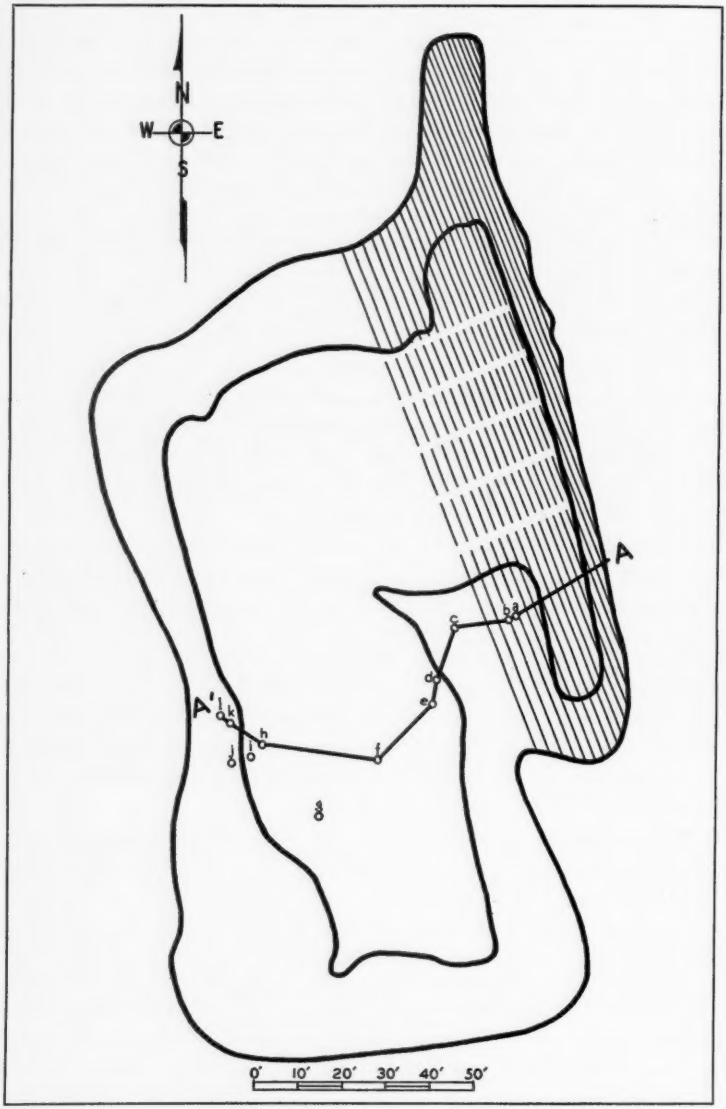

FIGURE 3.—*Outline of gravel pit on Hanagan ranch*

Shading indicates area of well-developed conglomerate at base of Clovis beds. (A-A') Line of section of Figure 4; (a to l) Location of measured sections.

(1933, p. 524; 1935, p. 79; 1936a, p. 333; 1936b, p. 407; 1936c; 1936d; 1936f; 1936g, p. 1329-1333; 1936h; 1937a, p. 111; 1939b); Richards (1936); Roberts (1937b, p. 157); Stock and Bode (1937); Woodward (1935, p. 406); Wormington (1939, p. 15-18).

Numerous artifacts have been found, including spears, knives, and scrapers. Among extinct animals present are elephant, horse, bison, camel, and peccary. The elephant has been identified by Stock and Bode (1937, p. 234) as *Parelephas* cf. *columbi* (Falconer) and the horse as *Equus* cf. *excelsus* Leidy.

Of the several localities in the Clovis area, the greater amount of material has come from a gravel pit on the P. H. Hanagan ranch. The geologic section at this pit, aside from the underlying bed rock, includes two formations; the older consists chiefly of gravel and sand with some sandy clays and in places, at the top of the formation, a caliche stratum. No fossils have been reported from this formation. Unconformably overlying these deposits is a formation consisting of several strata interpreted by the writer as follows: (1) At the east side of the pit, conglomerate consisting of sand, clay balls, and pieces of caliche is overlain by dark sand; the whole is replaced at the center of the pit by light sand and at the west side of the pit by "speckled" sand. (2) Above these deposits, an ash-like stratum containing diatoms grades at some localities into an impure diatomaceous earth; this stratum has been referred to in the literature as "ash-gray beds" and "blue sands." (3) At the top of the section is a brown sand stratum. The ash-gray beds and the overlying brown sand persist across the width of the pit; the ash-gray beds are found at all the localities yielding fossils in the Clovis area. This formation, consisting of the three horizons described, contains all of the fossils and artifacts found in the Clovis area. For these deposits Antevs proposed the term Clovis Lake clays. Since the formation includes sands as well as clays, the writer prefers the term Clovis beds.

That an unconformity exists in this section was commented on by the writer in letters to Stock and Howard in 1938. A section across the gravel pit is given in Figure 4. From this section it will be seen that a caliche stratum is present at the east side of the exposure. This caliche stratum is definitely under the unconformity; large pieces of the caliche up to one foot or more across have been reworked and included in the overlying deposits. In Figure 3, the part of the pit in which the unconformity is well marked by a basal conglomerate is indicated by shading. At the west margin of the pit where the conglomerate is wanting and where the "speckled" sand rests on loose sand or on sand and gravel, the unconformity cannot be readily recognized.

The writer's interpretation of the section is as follows: The sand and gravel of the formation below the unconformity is stream laid and very

possibly is part of an ancient stream terrace. The caliche stratum represents secondary accumulation of calcium carbonate at or near the original soil level, previous to the deposition of the overlying deposits. The presence of the caliche at this level is definite evidence, the writer believes, that the terrace containing the stream-laid gravel was a land surface

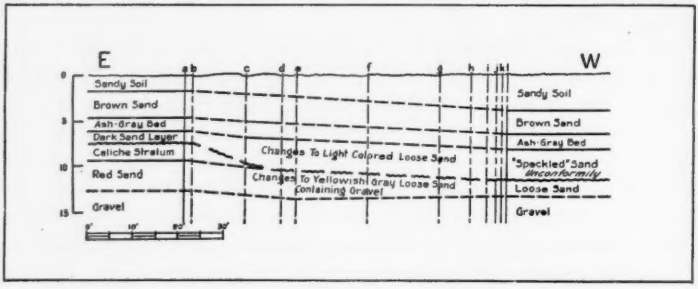

FIGURE 4.—*East-west section across gravel pit on line A-A' of Figure 3*
Reconstructed in part. (a to l) Location of measured sections.

subject to accumulation of caliche at soil level for a long period of time previous to the deposition of the overlying beds. The fossils and artifacts, as previously stated, are contained in the later deposits. This particular locality was apparently near the margin of a lake. The pieces of caliche and clay balls which are abundant in the conglomerate were washed from the nearby shores of the lake and were carried to their present resting place either by wave or stream action or both. This conclusion as to the relatively late age of the deposits holding the fossils and artifacts is in agreement with the conclusions of Howard, Antevs, Stock, and others. The unconformity within the section, however, which gives added support to this conclusion, although implied, seems not to have been previously commented upon. Frank Bryan, in a recent paper, has assumed that the fossils and artifacts at this locality are of the age of the stream-laid gravels and hence very ancient. With this conclusion, the writer, as indicated above, does not agree. On the contrary, the fossil-bearing beds, the writer believes, are of much later age than the underlying gravels, from which they are separated by an unconformity representing a long interval of time. The collections from this locality are in the University of Pennsylvania Museum and the Academy of Natural Sciences of Philadelphia.

Conkling Cavern.—Locality 14½ miles southeast of Las Cruces, discovered, 1929; announced, W. A. Bryan, 1929. Principal literature: W. A. Bryan (1929); Conkling (1932); Howard (1935, p. 146; 1936a, p. 332; 1936b, p. 405); Romer (1933, p. 80); Wormington (1939, p. 52-53).

Human remains were found in this cave at three levels at depths of 12, 21, and 52 feet. Remains of extinct animals were found at successive levels from 10, 12, and 52 feet (Conkling, letter of August 17, 1939). The extinct animals were in some instances in immediate association with the human skeletal remains. No artifacts were found. Among extinct animals obtained from this cave were *Nothrotherium, Camelops,* and *Equus.* Collections are in the Los Angeles Museum of History, Science, and Art.

Folsom.—Locality in a small stream valley occupied by an arroyo 28 miles southeast of Raton, New Mexico, discovered, 1926; announced, Figgins, 1927. Principal literature: Amsden (1931); Antevs (1935, p. 309); Brown (1928; 1929; 1932); Kirk Bryan (1929; 1937a, p. 140-143); Cook (1927a, p. 243-244; 1928b; 1931a, p. 102); Figgins (1927, p. 232-234); Hay and Cook (1930); Howard (1935, p. 145; 1936b, p. 407; 1936f; 1937b, p. 331); Renaud (1928, p. 43); Roberts (1937b, p. 153-157); Romer (1933, p. 79); Wormington (1939).

Sixteen or more artifacts have been obtained in immediate association with an extinct bison, *Bison taylori* Hay and Cook, and, according to Figgins (1933b, p. 21), *Bison oliverhayi.* However, Brown who has examined this bison material considers that *B. oliverhayi* is based on a female skull of *B. taylori* and hence is not a valid species (letter of September 5, 1939). Remains of some 40 or 50 bison were found within a small area representing, in the opinion of Brown, a bison kill by early man. A few fossils other than *Bison taylori* were obtained, all or nearly all of which are living species. This is the type locality for the Folsom culture. The age of the deposits, in the opinion of Brown, is late Pleistocene or possibly early Recent (1929, p. 129). Bryan considers the age as late Pleistocene. The collections from the locality are in the Colorado Museum of Natural History, Denver, and in the American Museum of Natural History, New York.

Sandia Mountain area.—Locality on east side of Las Huertas Canyon, in the northern part of Sandia Mountains, discovered, 1936; announced, Hibben, 1937. Literature: Hibben (1937).

Artifacts and a fireplace have been found in Sandia Cave. Among fossils found in the cave are horse, camel, and mastodon. The collections are at the University of New Mexico, Albuquerque.

Shelter Cave.—Locality on west flank of Bishop's Cap (Pyramid Peak), about 2½ miles west and south of Conkling Cavern in Organ Mountains. Literature: Stock (1930b; 1932).

This cave has yielded some relics of human occupancy. The relation of human materials to extinct animals has not been definitely determined.

NEW YORK

Lake Ontario.—Locality in village of Gaines, Orleans County, discovered about 1867; announced, Gilbert, 1887. Principal literature: Gilbert (1887); Holmes (1919, p. 79).

A hearth was found at depth of 15 to 18 feet in terrace deposits interpreted by Gilbert as belonging to the period of decline of glacial climate.

NORTH DAKOTA

Arvilla.—Locality in a gravel pit near Arvilla, discovered, 1908; announced, Jenks, 1932. Literature: Jenks (1935, p. 11-14).

Artifacts said to have been made of elephant ivory were obtained from burials. The collections are with Professor Jenks.

OHIO

Loveland.—Locality in a gravel pit in valley of Little Miami River near Loveland, discovered, 1887; announced, Wright, 1888. Principal literature: Holmes (1893b, p. 148-153); Leverett (1893, p. 188-189); Wright (1888a; 1888b, p. 258-259; 1890, p. 532; 1892, p. 250; 1893, p. 33).

An artifact is reported to have been found by Dr. Metz in a river terrace deposit at a depth of 20 or 25 feet. Two other objects which may or may not be artifacts were obtained from the same deposits. Mastodon bones were found in close proximity (Wright, 1892). The gravel deposits, according to Leverett, are of the age of the associated late glacial moraines of this region. Leverett was not convinced that the artifact could not have been in some way introduced into the deposits.

Madisonville.—Locality in a cistern in Madisonville, discovered, 1885. Principal literature: Abbott (1889, p. 296); Holmes (1893b, p. 153); Leverett (1893, p. 186-188); Wright (1888a, p. 432; 1888b, p. 257-258; 1890, p. 530-532; 1892; 1893, p. 32-33).

An artifact was found at a depth of about 8 feet at the contact of red clay on gravel. The red clay, according to Leverett, may be late Pleistocene, even post-glacial. No extinct animals were found in association with the artifact. The collection is in the Peabody Museum of Harvard University.

Miami River.—Locality in terrace of Miami River near Madisonville, discovered, 1885. Literature: Wright (1892, p. 250).

An artifact was found in a river terrace deposit at a depth of 8 feet.

Newcomerstown.—Locality in a gravel pit at Newcomerstown, discovered, 1889; announced, Wright, 1892. Principal literature: Holmes (1893b, p. 155-159; 1919, p. 80); Wright (1892, p. 251; 1893, p. 33-39).

An artifact is reported to have been found in a gravel pit at a depth of about 15 feet. No extinct animals reported.

OKLAHOMA

Afton.—Locality a spring at the head of a branch of Horse Creek, a tributary of Neosho River, near Afton, discovered, 1901. Literature: Holmes (1902b).

Many artifacts were found at this spring. The association of the artifacts with extinct animals is questioned by Holmes.

Frederick.—Locality a gravel pit on the A. H. Holloman farm, one mile north of Frederick, discovered, 1926 or earlier; announced, Figgins, 1927. Principal literature: Antevs (1935, p. 304); Cook (1927a, p. 244-247; 1927b, p. 116-117; 1928a; 1931b); Evans (1930); Figgins (1927, p. 234-239); Gould (1929b); Hay (1928a; 1929a); Hay and Cook (1930); Howard (1935, p. 145); Renaud (1928, p. 37); Romer (1933, p. 80); Sellards (1932); Spier (1928a; 1928b).

According to the operator, A. H. Holloman, several artifacts and fossils have been obtained. According to Hay and Cook, the fossils include the following genera: *Amyda, Camelops, Elephas, Equus, Felis, Glyptodon, Gomphotherium, Lama?, Megalonyx, Mylodon, Odocoileus, Ovibos?, Platygonus, Symbos?, Stegomastodon, Tapirus, Testudo?.*

The gravel pit is in the highest terrace of Red River in this region and is more than 150 feet above present water level in the South Fork of Red River, which is the nearest tributary. In lowering the drainage to the present level, successive terraces were formed, the youngest of which contains extinct animals. Four of these terraces have been named (Sellards) as follows, in order from the oldest to the most recent: Holloman, Hefner, Mitchell, and Davidson. The Holloman terrace is the one in which the artifacts are reported; the Davidson terrace is a broad low terrace adjacent to Red River and its tributary, North Fork. With the lowering of the drainage there occurred a westward or southwestward shifting of the North Fork of Red River. The exceptionally complete preservation of the terrace system in the vicinity of Frederick is due to the shifting of this tributary. On the opposite side, that towards which the North Fork has shifted, almost no high terrace deposits have been preserved.

The deposits of the Holloman terrace were, in the writer's opinion, sealed in Pleistocene time and remained undisturbed, except as erosion cut into the terrace at its east margin, until quarrying operations uncovered the gravel. Since the time when the terrace was formed, the Red River drainage system has lowered its level more than 150 feet in this part of the State. In the process of stream development extensive lower terraces were cut. The development of these terraces resulted in the partial destruction of the older Holloman terrace. Other and lower terraces down to the present Recent valley of the river attest the downcutting of the drainage system. The lowering of this part of the system, with associated terrace development, implies adjustment throughout much or all of the Red River drainage system. Erosion east and south of the present Holloman terrace has resulted in removal of the gravel and sand sheet which quite certainly extended beyond its present margin. An upland, which has since disappeared, necessarily bounded the terrace eastward. The Holloman terrace, under this interpretation, is Pleistocene and by no means the most recent Pleistocene of this region, since successively lower terraces down to or nearly to the present river likewise are Pleistocene.

If artifacts are present in the gravel deposits of the Holloman pit, and there seems to be no reason to question the observations of Mr. Holloman, they are unmistakably of Pleistocene age. The collections are in the

Colorado Museum of Natural History, the University of Oklahoma, and with A. H. Holloman, Frederick, Oklahoma.

OREGON

Fossil Lake.—Discovered, 1878; announced, Cope, 1878. Principal literature: Cope (1878; 1889, p. 970-982; 1895, p. 599); Howard (1935, p. 144; 1936b).

Artifacts at this locality are said to be "mixed with" bones of extinct animals. The extinct mammals listed are elephant, horse, camel, and sloth. Contemporaneity of the artifacts and fossils, in the opinion of Cope, is probable but not proven. Location of the collection is unknown.

Silver Lake.—Discovered, 1879; announced, Cope, 1889. Principal literature: Cope (1889); Howard (1935, p. 144; 1936b, p. 394).

Cope found camel, horse, and sloth in a lake bed associated with obsidian implements (Howard, 1935). The artifacts are in the U. S. National Museum, no. 148127. Some of the collection from Silver Lake is in the Smithsonian Institution, Washington, D. C.

SOUTH CAROLINA

Charleston.—Locality on banks of Ashley River about 10 miles upstream from Charleston, announced, Schmidt, 1872. Principal literature: Hrdlička (1907, p. 20); Schmidt (1872).

Human bones, artifacts, and pottery were reported to have been found by F. S. Holmes in association with mastodon. Details of occurrence and of the geologic conditions are wanting. The location of the collection is unknown.

TEXAS

Abilene.—Localities on Clear Fork of Brazos River and on Elm Creek in the vicinity of Abilene, discovered, Ray, 1929. Principal literature: Leighton (1936); Ray (1929; 1938); Sayles (1936); Wormington (1939, p. 44-45). An additional bibliography on these sites will be found in the Bulletin of the Texas Archeological and Paleontological Society.

Artifacts are found in alluvial deposits at varying depths up to about 30 feet. Burials made as the valleys were being filled by alluvial deposits are not uncommon. Extinct animals have been found in alluvial deposits similarly located on these streams. The collections are largely in the possession of Dr. Cyrus N. Ray and the Texas Archeological and Paleontological Society, Abilene.

Buckner Ranch.—Locality on the Buckner ranch on the right bank of Blanco Creek about 12 miles east of Beeville, Bee County, discovered, 1938.

Several artifacts have been found to a maximum depth of 16 feet in stream terrace deposits. Charcoal, burnt rock, and hearths are likewise present. Fossils found in immediate association include *Parelephas columbi* (Falconer), *Mastodon americanus* (Kerr), *Equus*, bison, and glyptodont. The collections are at The University of Texas. Excavations are in progress at this locality (Sellards, manuscript).

Cowan Ranch.—Locality on the Cowan ranch, 9 miles northwest of Miami, Roberts County, discovered, December, 1934; announced, Mead, 1935. Principal literature: Mead (1935); Sellards (1938); Studer (1935); Wormington (1939, p. 13-15).

Four artifacts were found in immediate association with the Columbian elephant, *Parelephas columbi* (Falconer). The collection is at The University of Texas and with J. A. Mead, Miami, Texas.

Hopper Ranch.—Locality on the Hopper ranch, about 11 miles southwest of Lipscomb, Lipscomb County, discovered, 1938.

Artifacts of the Folsom culture were found in association with extinct bison (Schultz, manuscript).

Lagow sand pit.—Locality Lagow sand pit, Dallas, discovered, October, 1920; announced, Shuler, 1923. Principal literature: Lull (1921); Shuler (1923).

Human bones were found in a gravel pit at a depth of 5 feet. The gravel deposits are part of a stream terrace, the top of which is about 50 feet above the flood plain of Trinity River. The overlying strata are reported to have been undisturbed. The degree of fossilization of the human bones is said to be about the same as that of the associated animal bones. The species identified from the sand pit are as follows (Lull): *Smilodon fatalis* (Leidy), *Odocoileus* sp., *Tetrameryx shuleri* n. gen. and sp., *Bison alleni* Marsh, *Camelops huerfanensis dallasi* n. subsp., camel, gen. and sp. indet., *Equus* cf. *E. fraternus* Leidy, *Elephas columbi* Falconer. The collection is at Southern Methodist University, Dallas, Texas, and at Yale University.

Lone Wolf Creek.—Locality on Lone Wolf Creek near the east city limits of Colorado, Mitchell County, discovered, 1924; announced, Cook, 1925. Principal literature: Cook (1925; 1926, p. 335-336; 1927a, p. 240-243); Figgins (1927, p. 229-231; 1935b, p. 4); Goddard (1926); Hay (1927b, p. 288); Hay and Cook (1930); Renaud (1928, p. 33); Romer (1933, p. 79); Wormington (1939, p. 26-27).

Three artifacts were found associated with the skeleton of a bison subsequently described as *Bison figginsi* by Hay and Cook. The artifacts and fossils occur in valley fill, now being rëexcavated by the present stream. The fossils occur a little above present low-water level. In addition to the bison skeleton, Cook (1927a, p. 241) obtained at a slightly lower level teeth of horse, camel, and elephant. The collections are in the Colorado Museum of Natural History, Denver, Colorado.

Lubbock.—Locality on United States highway No. 84 about 3 miles northwest of Lubbock.

Artifacts and fossil bones of bison and elephant were obtained and reported to the writer from the spoils bank of a canal by Adolph Witte in 1938. The locality is being excavated by the Department of Anthropology of Texas Technological College.

McLean.—Locality on a small stream tributary to Mulberry Creek about 30 miles southwest of Abilene, discovered, July, 1938; announced, Bryan and Ray, 1938.

Principal literature: Kirk Bryan and Ray (1938, p. 263-268); Ray and Kirk Bryan (1938, p. 257-258); Wormington (1939, p. 15).

A spear point was found closely associated with part of a skeleton of an elephant, *Parelephas columbi* (Falconer). The collection is in the possession of the Texas Archeological and Paleontological Society, Abilene, Texas.

Malakoff.—Locality near Malakoff, Henderson County, discovered, 1929; announced, Sellards, 1930. Literature: Sellards (1930).

In 1929 a stone, rudely carved to represent the head of man, was found at the base of a gravel pit at a depth of 16½ feet (Sellards). A second similar carved stone was found in 1935 and a third in 1939 (Sellards, manuscript). Associated fossils include sloth, horse, elephant (*Parelephas columbi*), camel, and bison. Excavations are in progress at this locality. The collection is at The University of Texas.

Round Rock.—Locality on Brushy Creek near Round Rock, Williamson County, discovered, 1934; announced, Pearce, 1935. Principal literature: Pearce (1935); Sellards (1935; 1936).

Artifacts have been found in stream terrace deposits. No extinct vertebrates have been found in immediate association with the artifacts. The collection is at The University of Texas.

White Rock Creek.—Locality in the valley of Brazos River in McLennan County. Literature: Frank Bryan (1931).

Frank Bryan reported finding an artifact at a depth of 40 feet in a gravel pit. The elephant is an abundant fossil at this locality.

SOUTH AMERICAN LOCALITIES

GENERAL DISCUSSION

A discussion of South American localities of early man reported previous to 1912 will be found in a publication by Aleš Hrdlička in collaboration with W. H. Holmes, Bailey Willis, F. E. Wright, and C. N. Fenner (1912). Later publications on the same subject are those of Sir Arthur Keith (1925; 1931), Walter, Cathoud, and Mattos (1937), Spillman (1936), and Bird (1938).

CHILE

Fell's Cave.—Locality in a shelter cave in the valley of Río Chico, north of Magellan Strait and east of Laguna Blanca. Literature: Bird (1938).

A layer 3 to 9 inches thick at the bottom of the cave deposit contained fire hearths, stone flakes, rubbing stones, stone and bone artifacts, and broken and burnt bones of horse, sloth, and guanaco. The next overlying stratum formed by rock caving from the roof is 16 to 28 inches thick and is sterile. Above this layer the horse and sloth were absent and the artifacts were unlike those below.

Palli Aike Cave.—Locality 20 miles east of Fell's Cave. Literature: Bird (1938).

Broken and burnt bones of horse and ground sloth were found with occupational refuse including stone and bone tools. At a lower level were found charcoal and stone flakes and seven sloth skeletons.

ECUADOR

Punin.—Locality near Riobama, discovered, 1923; announced by Anthony in 1925. Principal literature: Anthony (1925).

The fossil was found in a volcanic ash bed containing a Pleistocene fauna. Among common species of this deposit, according to Anthony, are the following: *Equus andium* (?), *Dibelodon andium, Mylodon* sp. (?), *Protauchenia, Arctotherium* sp. (?), *Smilodon* sp. (?). Of this occurrence, Anthony says:

"Serious consideration must be given to the implied contemporaneity of this cranium with the Pleistocene species of the Punin beds."

The collections are in the American Museum of Natural History, New York.

Alangasi.—Locality near the village of Alangasi, about 13 kilometers east of Quito, Ecuador. Principal literature: Spillman (1936); Osborn (1936).

Spillman reports that in April, 1928, he found a complete skeleton of a mastodon associated with potsherds, fireplace, and spear heads. The bones of the animal were charred. The evidence is said to indicate that the animal had been killed and roasted by man and that the event occurred in Recent time. Osborn (1936, p. 571) identified this mastodon as *Cuvieronius* (*Bunolophodon*) *postremus.*

SUMMARY OF PRINCIPAL EXTINCT MAMMALIA ASSOCIATED WITH HUMAN REMAINS IN NORTH AND SOUTH AMERICA

ELEPHANT

The presence of man in America previous to the extinction of the elephant on this continent has been fully established. The elephants most commonly reported with man's remains are those of the species or group of *Parelephas columbi* (Falconer). The definite association of this or a closely related species with artifacts has been established by Howard (1933) at Clovis, New Mexico, and by the writer (1938) at the Cowan Ranch locality in Roberts County, Texas. This association has also been recently observed by the writer at the Buckner Ranch locality in Bee County, Texas, and at the Malakoff locality in Henderson County, Texas. Other localities where this association has been observed are Vero and Melbourne, Florida (Gidley, 1927; Loomis, 1924; Sellards, 1937); McLean, Taylor County, Texas (Ray and Bryan, 1938); and Las Vegas, Nevada (Simpson, 1933; Harrington, 1934a). The association at

Dent, Colorado, is probably with this species (Figgins, 1933a, p. 7). This species occurs also at Frederick, Oklahoma (Hay and Cook, 1930), and at the Lagow sand pit, Dallas (Shuler, 1923).

Several other occurrences of elephants associated with human remains have been reported. Williston (1905a) states that the marl deposits overlying the blue clays in which the artifact was found by Martin at Russell Springs, Kansas, contains the woolly elephant, *Mammonteus* (*Elephas*) *primigenius* (Blumenbach). Sinclair (1904) reports that this species is present in the Potter Creek Cave in which were found the pieces of bone identified by Gidley, Matthew, and Putnam as worked by man. The imperial elephant, *Archidiskodon imperator* (Leidy), is reported by Bowden and Lopatin (1936) as occurring in the same deposits as the human skeletal remains near Los Angeles, California. Osborn (1932) has identified the elephant found associated with artifact at Angus, Nebraska, as *Archidiskodon meridionalis nebrascensis*. An elephant, species not identified, has been reported in deposits above artifacts at Whitewater Creek, Arizona (Antevs, personal communication). Hay (Hay and Cook, 1928) has described a new species of elephant from the gravel deposits reported to contain artifacts near Frederick, Oklahoma. The elephant is reported also from Lake Lahontan, Nevada, in deposits from which McGee obtained an artifact.

MASTODON

Mastodon remains have been found in association with human remains at several localities in North and South America. The species represented in most, if not all, instances in North America is the American mastodon, *Mastodon americanus* (Kerr). The first reported occurrence in North America of extinct animals in association with man, of which the writer has found record, was by Koch (1839a), who claims to have found in October, 1838, a mastodon skeleton and associated artifacts in the valley of Bourbeuse River in Gasconade County, Missouri. The next year, a similar discovery, according to Koch, was made in the valley of Pomme de Terre River in Benton County, Missouri. In South Carolina, Holmes although he did not publish on the subject, is said to have found artifacts, including pottery, in association with mastodon remains. Dickeson (1846) believed that human skeletal remains were derived from the same stratum as were the mastodon and other fossils obtained by him at Natchez. In 1916, the American mastodon, along with other extinct species, was found in association with human remains at Vero, Florida (Sellards, 1916a), and later, under similar conditions, at Melbourne Florida. Hibben (1937) reports *Mastodon* in association with artifacts at Sandia Cave, New Mexico. This species is present also in Potter Cave,

California. In Ecuador, South America, Spillman (Osborn, 1936, p. 571-574) reports a mastodon skeleton associated with spear heads, potsherds, and a fireplace, representing, in the opinion of Spillman and others, a relatively recent feast on roasted mastodon.

SLOTHS, ARMADILLOS, AND GLYPTODONTS

One of the early reported discoveries in America of man associated with extinct animals was by Lund at Lagoa Santa in Brazil, South America. In caves on the shore of Lake Sumidouro in the province of Minas Geraes, Lund from 1835 to 1846 found what he believed to be evidence of human habitation contemporaneous with ground sloth and other animals now extinct. According to Walter, Cathoud, and Mattos, new investigations are being made of caves of the Lagoa Santa region. The genus *Glossotherium* has been reported in association with human remains at Eberhardt Cave of Ultima Esperanza, near Last Hope Inlet, Patagonia (Stock, 1931, p. 23). Bird (1938) found fossil ground sloth associated with artifacts in Fell's and Palli Aike caves in Chile.

In North America, *Megalonyx*, has been found at Vero and Melbourne, Florida; Frederick, Oklahoma; Potter Cave, California; Malakoff, Texas; and Natchez, Mississippi. *Mylodon* has been found at Melbourne, Florida; Frederick, Oklahoma; and Natchez, Mississippi. *Chlamytherium* and *Dasypus* have been found at Vero and Melbourne, Florida; and *Glyptodon* at Frederick, Oklahoma, and Melbourne, Florida. A striking find of human skeletal remains in association with sloth was made in 1929 at Conkling Cavern in New Mexico. At this cave the human remains are found with and below sloth remains, genus *Nothrotherium*. This sloth has been found also in Gypsum Cave, Nevada.

HORSE

In the southern part of the United States, horses of several species occur in relative abundance in deposits containing human remains. The following are some of the localities in North America at which fossil horse of the genus *Equus* has been found with or near man's remains or artifacts: Buckner Ranch, Malakoff, Lagow sand pit, and Lone Wolf Creek, Texas; Burnet Cave, Clovis, Conkling Cavern, and Sandia Mountain area, New Mexico; Melbourne and Vero, Florida; Gypsum Cave, Smith Creek Cave, Lake Lahontan, and Las Vegas, Nevada; Whitewater Creek, Arizona; Natchez, Mississippi; and Frederick, Oklahoma. Bird (1938) found fossil horse associated with artifacts in Fell's and Palli Aike caves in Chile.

BISON

Extinct bison, of several species, have been found in association with human remains at many localities on the North American continent.

Bison are present at the Natchez locality. In 1895 an artifact was found associated with an extinct bison at Russell Springs, Kansas (Williston, 1902a). In Nebraska in recent years, a similar association has been recorded at Bridgeport, Crawford, Cumro, Grand Island, and Scottsbluff; in Minnesota at St. Croix Valley and Lake Itasca localities; in New Mexico at Burnet Cave, Folsom, and Clovis; in Florida at Melbourne; in Nevada at Las Vegas; and in Texas at Lone Wolf Creek, Buckner Ranch, Malakoff and at the Hopper Ranch localities.

CAMEL

Camel remains, chiefly, but not entirely, of the genus *Camelops*, have been found with or near human remains or artifacts at the following localities in North America: Gypsum Cave, Las Vegas, Smith Creek Cave, and Lake Lahontan, Nevada; Burnet Cave, Conkling Cavern, Clovis, and Sandia Cave, New Mexico; Lagow sand pit, Texas; Vero and Melbourne, Florida; Frederick, Oklahoma; Whitewater Creek, Arizona; and Malakoff, Texas.

OTHER EXTINCT MAMMALS, BIRDS, AND REPTILES

Among other extinct mammals reported with or near human remains or artifacts from more than one locality are the following: Tapir, Vero and Melbourne, Florida, and Frederick, Oklahoma; dire wolf, Vero and Melbourne, Florida, and Whitewater Creek, Arizona; sabre-tooth tiger, Vero, Florida, and Lagow sand pit, Texas; peccary, Russell Springs, Kansas, Potter Creek Cave, California, Melbourne, Florida, Clovis, New Mexico, and Frederick, Oklahoma; *Odocoileus sellardsiae* at Vero and Melbourne, Florida. *Castoroides ohioensis* has been found at Bridgeport, Nebraska, and the cave bear, *Arctodus*, at Burnet Cave, New Mexico. *Gomphotherium* sp. and *Stegomastodon* sp., found in the gravel pit at Frederick, Oklahoma, should be mentioned as possible associates of man's remains. Several other extinct species are listed in the Burnet Cave, Potter Creek Cave, Vero, and Melbourne faunas. The extinct stork *Jabiru weillsi* Sellards from Vero has not as yet been found elsewhere. This is true also of three other new species of birds found at Vero, described by Shufeldt. A new bird is reported by Harrington from Smith Creek Cave. From the Vero deposits Hay has described several extinct turtles.

MARKINGS ON FOSSIL BONES AND STONES

The writer has called attention to and illustrated markings on a proboscidean tusk and on fossil bird bones from Vero, Florida; the markings are believed to have been made by man (Sellards, 1916c, pl. 22). Roberts has briefly described markings on fossil bones from Lindenmeier which he

regards as having been made by man. These bones, according to Roberts (1939, p. 103), bear "incised lines indicating that the people had a simple form of geometric art." Eddy and Jenks report knife marks on bones of caribou and *Bison antiquus* Leidy, found in the valley of St. Croix River, Minnesota. Cook (1931a, p. 102) found markings which he believes were made by man on elephant and bison bones from Yuma, Colorado. Among proboscidean and other fossil bones obtained near Winter Beach, Florida, are some that show what appear to be marks of flint knives made in cutting the flesh from the bones. From gravel pits at Malakoff, Texas, three images rudely carved in stone have been obtained by the writer. These will be more fully described when excavations, which are now in progress, have been completed.

CONDITIONS OF OCCURRENCE

Remains of early man occur in the Americas under varied conditions, such as peat, glacial outwash, loess, cave, stream terrace, lake, and blanket or formation deposits. The remains of mastodon and man in or under peat deposits have been reported at a few localities. At Worcester, Massachusetts, Putnam (1885) found man and mastodon skulls at the base of a 6-to 8-foot peat deposit. In recent years Burmaster (1932) has found mastodon and an artifact at the bottom of peat deposits at Cromwell, Indiana. Since the rate of formation of peat deposits is unknown, there is little information on which to estimate the actual age of such remains, and, accepting the association as proven, it is still as much a question of the recency of the extinction of the mastodon as of the antiquity of man. The writer has found the mastodon in the lowest and latest terraces of the Texas streams, and there is, likewise, the observation of apparently very recent mastodon in South America (Osborn, 1936).

The occurrence of human remains in glacial outwash and loess deposits has been vigorously contested. Classic localities are the relatively recent finds by Jenks and associates in Minnesota and, in loess deposits, the finds at Lansing, Kansas. At the Minnesota locality, very strong evidence is presented for the glacial age of the human remains. At the Lansing locality, the question at issue is as to whether the loess deposits are original or reworked. Artifacts have been reported from loess deposits at Walkerville, Illinois (McAdams, 1881), Muscatine and Sioux City, Iowa (Witter, 1892; Aughey, 1876), and at Omaha, Nebraska (Aughey, 1876).

Striking results have been obtained from exploration of caves in the United States in recent years. Particularly instructive are the finds obtained from Burnet Cave by Howard and associates; from Conkling

Cavern by Conkling and W. A. Bryan; from Sandia Cave by Hibben—all in New Mexico; and from Gypsum Cave in Nevada by Harrington and associates. In all of these caves extinct animals are more or less definitely in association with man's remains. Potter Creek and Samwell caves in California should also receive consideration in this connection. The proof of age in these caves rests chiefly on this association, although in Conkling Cavern there is a depositional record; the uppermost deposits contain human remains and sloth and are separated by a hard rock stratum from the lower deposits, which also contain human remains and associated fossils. However, the age determination in caves rests primarily on the faunal association.

The lake deposits of Arizona, California, and Nevada have afforded much new information. Whitewater Creek, Arizona (Antevs, 1937b), and Clovis, New Mexico (Howard, 1933), afford proof of association of man with extinct animals under climatic conditions differing from those of the present time. Several other localities—Borax Lake, Lake Mohave, and Pinto Basin, California—indicate the presence of man under conditions of greater moisture than exist in the same region at the present time. Lake Lahontan is a classic locality of reported artifact and extinct animals in the late history of that lake.

Stream terrace deposits in relation to human history are discussed in a subsequent section. With the active developments of recent years, many stream terrace deposits containing human remains are now known. Two localities containing human materials in blanket or formation deposits are Melbourne and Vero, Florida. To these is probably to be added the Winter Beach, Florida, locality, mentioned in this report. The formation from which the oldest human materials come at these localities is the Melbourne bone bed, as defined by Cooke and Mossom (1929, p. 218). This formation is Pleistocene in age.

TIME OF EXTINCTION OF CERTAIN MAMMALIAN SPECIES

One or two decades ago, the discussions on early man in America centered around the alleged discovery of remains or artifacts with extinct animals. It was then commonly assumed that the proof of man's association with extinct species would of itself be conclusive proof of the presence of man in America in the Pleistocene. In recent years, the proof of this association having been established, the discussion has shifted to the possible recency of the extinction of the animals. Formerly the animals themselves were supposedly competent witnesses as to age of deposits. Now that their competency is called into question, these animals can no longer serve as index fossils, and supplementary proof of age must be found elsewhere.

STREAM TERRACE DEPOSITS

Several years ago the writer emphasized the fact that stream terraces afford definite evidence of relative age of deposits and that man's remains may sometimes be obtained from these terrace deposits under conditions that will establish relative age and to a degree actual age (Sellards, 1936). Since that time progress has been made in the study of terrace deposits with the result that a better understanding is being obtained both as to the age of man and as to the range of species. Bryan (1937a, p. 148-149) has shown that the Folsom culture of the Lindenmeier site in Colorado is found in deposits which, traced downstream, become a terrace about 20 feet above stream grade, this being one of the terraces of tributaries of Boxelder Creek. These deposits, continued to Cache la Poudre River, become the 25-foot terrace of that stream and the 30-foot terrace of South Platte River.

During the past year the writer has demonstrated the presence of artifacts in the 25-foot terrace of Blanco Creek in Bee County, Texas, at the Buckner Ranch site. Among the artifacts of this locality are Folsom, Yuma, and other points, the culture being of Folsom age or later. Terraces vary in height with size of stream, and since the terraces on the small streams at the Lindenmeier and Buckner sites are so nearly of the same height, it is probable that the two localities are of the same geologic age or nearly so. The Malakoff locality of Henderson County, Texas, to be described in a later paper, lies in an older terrace. Stream terrace deposits in Nebraska are being actively studied by several investigators. The highest terrace from which artifacts have been reported is the Holloman terrace at Frederick, Oklahoma. This terrace is more than 150 feet above present water level in the adjacent streams (Sellards, 1932). It is certain that definite developments in the study of early man in America will be obtained from further study of stream terrace deposits and their fossil content, including man's remains.

SUMMARY

The evidence now available proves that man has had a long continued existence in America, and that he was contemporaneous in the Western hemisphere with a considerable number of mammals and some birds and reptiles now extinct. The evidence of this association is derived from field observations by many observers at various localities under varied conditions of occurrence.

The age determination of human remains and artifacts is based not only on associated fossils but likewise on a study of the physiographic features, particularly the position of the stream terrace deposits in which the human relics and fossils are found.

The fact that all human skeletal parts thus far obtained in America are referred to the modern species does not preclude the possibility of their being of Pleistocene age since many vertebrate species other than *Homo sapiens* continued from Pleistocene to the present time. On the contrary there are many records indicating the presence of man in America previous to the close of the Pleistocene period and under climatic conditions differing from those of the present time. Man is present in the Pleistocene of America.

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ECOLOGY OF MODERN MARINE ORGANISMS WITH REFERENCE TO PALEOGEOGRAPHY

BY THOMAS WAYLAND VAUGHAN

(*Address as retiring President of the Geological Society of America*)

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INTRODUCTION

In this address emphasis will be placed not on the utilization of the remains of marine organisms in solving problems of stratigraphic correlation, but on the value of the knowledge of them in attempts to reconstruct the physical and chemical conditions prevalent in the seas of the past. The area of the oceans of today constitutes about 70 per cent of that of the surface of the earth. Inspection of geological maps of large areas, such as those of continents, reveals that approximately 70 per cent of the land surface of the earth is formed by rocks of marine origin. Deposits of marine origin of Recent and ancient ages form about 90 per cent of the surface of the lithosphere. In comparison with the length of the radius of the earth, the thickness of the marine sediments is slight, at most only a relatively few miles, but these rocks contain the record of many, if not most, of the geological events that have transpired on the surface of the earth. If we are to understand those events we must develop as far as possible the basis of the interpretation of the features presented by sedimentary rocks.

Recently there has been great activity and advance in the study of the physical features of the earth, due to progress in numerous lines of research and to the invention of many kinds of instruments of precision. It is not intended to review these accomplishments here, but it is desirable to call attention to the developments of methods for the measurement of gravity, especially at sea; the application of seismic methods for the measurement of the thickness of rock masses and the determination of the presence of discontinuity layers; and the progress in the study of the magnetism of rocks. There has also been notable advance in the study of igneous rocks, the mechanism of volcanic activity, and other physical and chemical phenomena, but efforts to build a solid foundation for the interpretation of the organic features of sedimentary rocks have lagged.

EARLIER INVESTIGATIONS

The need of studying the sea as the site of many geological phenomena was long ago recognized. Edward Forbes in 1843 presented at a meeting of the British Association for the Advancement of Science a paper entitled *Report on the Mollusca and Radiata of the Aegean Sea, and on their*

distribution, considered as bearing on geology. He recognized eight depth zones, each characterized by a peculiar assemblage, a community, of organisms, but he was wrong when he thought that animals did not extend to depths below 300 fathoms.

In many books there are excellent accounts of some of the relations of organisms to certain conditions in the sea. For example in Jules Richard's *L'Océanographie* (1907) chapter 10-15, are devoted to "Océanographie biologique." In the first of these he defines the terms "benthos," "plankton," and "nekton." Subsequently in the same chapter he recognizes littoral, coastal, and abyssal regions, and he discusses the relations of marine organisms to several other factors. After the general chapter, he devotes one chapter to marine plants and four to marine animals. Somewhat similar treatment is found in other books on oceanography, such as Johnstone's *Introduction to oceanography* (1923), and in volumes by Sir John Murray (1912, 1913). Schott in his geographies of the Atlantic Ocean (1926) and of the Indian-Pacific Ocean (1935) has in each work a chapter on biology.

In Hesse's *Tiergeographie auf ökologischer Grundlage* (1924), and in its English edition *Ecological animal geography* by W. C. Alee and Karl P. Schmidt (1937), a section is entitled "Die Verbreitung der Meerestiere" in the German original, and "the Distribution of marine animals" in the English edition. S. Ekman's *Tiergeographie des Meeres* (1935) needs mention. These works contain valuable and usable information, but they do not supply a basis for the interpretation of the floras and faunas represented in marine sedimentary rocks.

Johannes Walther's *Bionomie des Meeres* and *Lebensweise der Meerestiere* are justly rated as classics. The fundamental plan of Walther's treatment is not greatly different from the one I am advocating, but Walther's work was published in 1893 and 1894, more than 45 years ago, and since then we have learned much. Two other volumes that deserve mention are Carl Diener's *Grundzüge der Biostratigraphie* (1925) and Hermann Schmidt's *Die bionomische Einteilung der Meeresboden* (1935). Attention should also be called to the symposium on *Criteria in Paleozoic Paleogeography* organized by Charles Schuchert (1910) while he was president of the Paleontological Society of America, and to the discussion of paleoecology organized by W. H. Twenhofel in 1936 and 1937 (mimeographs, U. S. Nat. Res. Council). Other significant papers will be mentioned later in this address.

This review of previous work cannot now be further pursued. There are many valuable contributions, but the needs for interpreting the paleontological record are not met.

FORMULATION OF THE PROBLEM

This part of my discourse will be introduced by recounting an experience I had between September 1889 and June 1892. During that time I was a teacher in northwest Louisiana in a junior college which was situated on a bed that contained middle Eocene marine fossils. Near-by there were good exposures from which a moderately large fauna was obtained. The question then raised was what were the conditions in the sea in which those animals lived? At that time I had had only a beginner's course in geology, and my knowledge of the ocean was restricted to a round-trip steamer voyage from New Orleans to New York and an excursion on a boat around Boston Harbor. I knew but little geology and less of the ocean, but I got information and collections enough, supplemented by some additional field work, for my first two geological papers. The question, what kind of a sea did those animals live in, stayed with me and it determined much of what I was to do in later life. Many others had asked similar questions and had tried to provide answers. Many are still asking the same kind of questions, and some are trying to answer them.

In dealing with a sea, among the questions to be asked are, what was the nature of the bottom, what was the depth, and what was the temperature of the water? Did the organisms live at or along the shore, near the shore, or at some distance from it? Did they live in quiet, in moderately agitated, or in strongly agitated water? What was the nature of the general movement of the water? What was the chemical composition of the water, the relative quantity of salts in solution, and the amount of available oxygen in it, its probable hydrogen-ion concentration, and the oxidation-reduction potentials of the bottom material? What plant nutrients were in solution and available for plant life, and what probably constituted the basic food supply of the purely animal feeders. We should like to have for each ancient marine geological formation the same kind of information that we can get for the geological formations now in process of formation in the sea.

Since we are trying to decipher conditions in past seas, seas which no longer exist, it is obvious that the answers to the questions regarding those seas cannot be found in them. The only available seas are the modern seas, and to them we must go and study them with the purpose in mind of building a basis for interpreting the records left by the ancient seas. In the modern seas there is a great variety of conditions, a variety of environments, and, for each environment suitable for life, there are organisms adapted to it. We must ascertain what those environments

are, classify them in some orderly way, and find out what organisms belong with each of them. The biological characterization of environmental types may be approached in two ways. One is to try to ascertain as nearly as is practicable the entire organic assemblage for each environmental category. The other is to study one large group of organisms throughout the range of its occurrence in the sea.

The problem set for this address is to sketch the types of marine environments in existing seas and to indicate how they may be biologically characterized, in order that a better foundation may be built for interpreting the records made by the ancient seas. All that may reasonably be expected are sketches and suggestions. Full treatment of the subject would require a large volume.

LIMITATION OF THE RECORDS OF LIFE IN ANCIENT SEAS

Before proceeding to more detailed consideration of special subjects, it should be said that except under unusual conditions the only organic remains found in geological formations are the calcareous or siliceous hard parts of organisms. Jellyfish, horny sponges, sea anemones, tunicates, most worms, and other animals without hard parts very rarely leave any geological record. The only marine plants common as fossils are diatoms and coccolithophorids, and calcareous algae of two groups, the Codiaceae and the nullipores or lithothamnia (Corallinaceae). The animal groups of most value are the Foraminifera, Radiolaria, siliceous and calcareous sponges, some hydrozoans, corals of the three recognized large groups, echinoderms, brachiopods, bryozoans, crustaceans, molluscs, and elasmobranchs. Marine bony fishes and reptiles are rare as marine fossils, but the remains of mammals are abundant in some places and they supply great help in solving problems of correlation across bodies of ocean water. These are the groups to which the geologist must pay most attention.

MIXED ASSEMBLAGES

There is an aspect of fossil organisms that will be mentioned in a cursory way. The organisms found in the fossil state are dead—in fact we do not find the organism but what was some part of it, and that part may or may not have been greatly changed. The aggregations of fossil organisms found in definite places have been called "death assemblages." The implication is that such assemblages may be misleading as to what the living assemblages were. I feel no greater uneasiness about being misled by the mixing of organisms of different environments in a fossil fauna or flora than by being misled by mixtures found in Recent faunal

aggregates. Some members of this Society will recall J. F. Kemp's joke that "geologists must know beans." Kemp (1919) had noticed on a beach in Florida a mixture of the remains of organisms of diverse habitats, including beans that had drifted northward from somewhere in the tropics farther south.

In the sea, organisms that have hard parts are usually divisible into about four categories: (1) Those fixed to the bottom and immobile; (2) those that creep or walk; (3) those that swim; and (4) those that float. Mixtures are caused by some kind of transport from one place to another. Transport is accomplished by wind, waves, or currents. In shallow water, organisms, such as Foraminifera, get washed up on the beach and there are dried out. A strong wind may pick up the light shells and carry them for miles. Thus is probably to be explained the presence of specimens of shallow-water *Peneroplis* in water 800 fathoms deep, in The Tongue of the Ocean in the Bahamas. Some aggregates, such as Globigerina, diatom, radiolarian, and pteropod oozes are almost entirely composed of the remains of floating organisms, whose skeletons after death settle to the bottom. The tests of some pelagic organisms are carried by winds, waves, and currents not merely into shallow water but even up on beaches, or they may fill interstices between coral heads and masses of nullipores. On the other hand during storms the bottom near shore may be eroded in water of moderate depth, a few tens of feet, and organisms from such depths may be washed ashore and mixed with other organisms of littoral or shallow-water habitat.

Mixture of another kind is caused by the movement of material by wave or current action from higher to lower levels. Material may be broken from the edge of a precipice and build up a talus slope or apron at the base. Murray wrote a good deal about such submarine talus, especially in explanation of the seaward extension of coral reefs. Material may also be carried into deeper water along gentler declivities.

Except along shore, or very near shore, the admixture in modern seas of organisms of different environments is not great, if we exclude the pelagic deposits. From my considerable geological field experience, it seems to me that such mixtures are not of so frequent occurrence as to be very perturbing in the study of most fossil faunas. There are numerous criteria for deciding whether organisms are *in situ*. For example, if the two valves of pelecypods are in place and are buried in their natural positions in a stratified deposit, it is a safe inference that the animal has left a record of the ecologic conditions prevalent at the place where it lived and died. There are other criteria, but the subject cannot now be further pursued.

MARINE ENVIRONMENTS

GENERAL COMMENT

In the initial characterization of marine environments, it must be recognized that in the ocean there is a bottom of diversified relief; on it there is a range in temperature from below 0° to 33° C; and the material on its surface comprises all kinds from conglomerates, organic reefs, and oozes of aragonite needles at and near shore to the red clay of the abysses. The illumination of the bottom ranges from the maximum strength of sunshine at sea level to the utter darkness of oceanic depths. Of the variables in the sea there is only one, the bottom configuration, that approximates an independent variable. All others are functions of something else.

Between the bottom and the surface there may be but little water or there may be miles of it, up to almost 35,000 feet in the deepest places in the Pacific. These bodies of water vary greatly in their physical and chemical properties, but they contain organisms which are more abundant near the surface than deeper down. In this region there are wide ranges of environments different from those of the bottom.

When we come to the surface we encounter another complex of environments. Floating microscopic plants thrive, where plant nutrients are available, to the depth of the light floor. The plants are followed by animals of different kinds that feed on them; and the smaller are eaten by larger animals. The carcasses of various organisms at and near the surface sink and contribute food to those at lower levels, even to the bottom. The surface of the sea presents variety especially in temperature and the quantity of solutes needed by organisms. The remains of planktonic organisms, coccolithophorids and diatoms among the plants and pelagic Foraminifera, Radiolaria, and pteropods among the animals, form on the ocean floor widespread deposits of significance to the geologist. Features of these deposits are indices of the physical conditions at the surface of the sea in which the organisms lived.

For geologists generally the bottom-living organisms are the more important, but this is not intended to imply that consideration should not be given to planktonic and nektonic organisms.

DEPTH ZONES

Figure 1, copied from Sir John Murray, illustrates the general relations off such a shore as that of the Atlantic Coast of the United States.

There is the actual shore line, between high-tide and low-tide levels, the intertidal zone; below that there is the neritic zone, which is supposed to extend to about 100 fathoms, 180 meters, the edge of the continental shelf and the approximate position of the light floor; from a depth of about 100 fathoms to 1000 or more fathoms is the continental slope; and at still

lower levels there are the oceanic abysses, which are now known to be of more varied relief than was supposed 25 or 30 years ago.

According to this scheme there are four depth zones. These zones are convenient but they need subdivision as will be made clear later in this

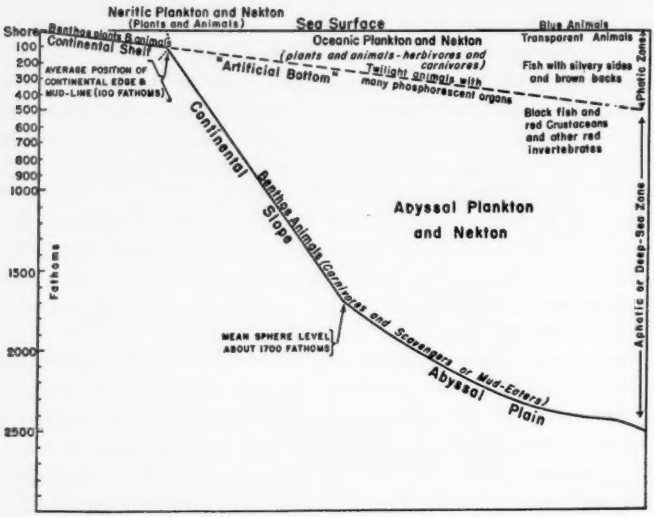

FIGURE 1.—*Diagram showing the oceanic faunal and floral areas.*
After Sir John Murray.

address. The intertidal zone needs subdivision into at least three zones; in the foraminiferal faunas off the coast of southern California, Natland defines five zones, and there is neither a tropical nor a subtropical fauna there. Other examples might be given. The so-called neritic zone needs subdivision into two or more zones.

Table 1, copied from Sir John Murray (1913, p. 182), is pertinent here. The Protozoa are not included in this table, and the number of individuals in water less than 100 fathoms is not given because of the difficulty in estimating the number captured. Murray attached much importance to what he calls the "mud-line", the average depth of which is about 100 fathoms. This is where the minute organic particles in the water settle to the bottom and form a great feeding ground.

OCEANIC CIRCULATION

Since the distribution of temperature in the ocean is largely controlled by oceanic circulation a brief account of the major features of the circula-

tion will be outlined. In each ocean that extends from one polar region to the other there are two gyrals, one in each hemisphere. A combination of agencies causes water at and near the surface to move westward in tropical and subtropical latitudes. Near the equator there are in each

TABLE 1.—*Bathymetric distribution of benthonic species collected by the* CHALLENGER (After Sir John Murray.)

Zone of depth (Fathoms)	Number of stations	Number of individuals	Number of species	Number of genera	Ratio of species to genera	Species taken only in the zone referred to	
						Number	Per cent
Less than 100	70	.....	4250	1440	2.93:1	3900	92
100 to 500	40	6000	1893	776	2.37:1	1408	74
500 to 1000	23	2000	631	363	1.67:1	406	64
1000 to 1500	25	2000	508	327	1.50:1	277	55
1500 to 2000	32	1250	412	272	1.45:1	249	60
2000 to 2500	32	820	262	184	1.36:1	165	63
More than 2500	25	600	161	127	1.17:1	96	60

hemisphere westward-moving equatorial currents, which because of the deflecting effect of the earth's rotation and the land masses on the west sides of the ocean basins are bent northward in the northern and southward in the southern hemisphere. The deflection continues until in higher temperate latitudes the water at and near the surface moves eastward. In the northeastern North Atlantic some warm water crosses the ridge between Iceland and the islands north of Scotland and enters the Norwegian Sea and produces the mild climate of southern Scandinavia. There is a reversed circulatory curve in the Gulf of Alaska and it is responsible for the mild climate of southern Alaska. The main water movements, however, continue toward the continental masses on the east sides of the ocean basins, with continued deflection toward the equator, ultimately completing the gyrals mentioned. Between the North and South Equatorial currents in the Pacific Ocean there is a well-developed Equatorial Counter Current, but such a current is not so definite in the Atlantic.

In low temperate latitudes on the west side of each continent there is upwelling of cold subsurface water from depths of a few hundred meters. Famous regions of such upwelling are the coasts of California, Peru, and

western Africa. On the east sides of the continents of Asia and North America in temperate latitudes there are inshore counter currents that flow southward and produce cooler water along and near shore than farther seaward.

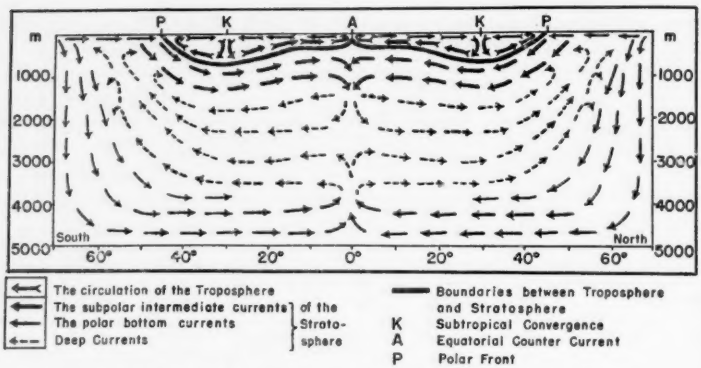

FIGURE 2.—*Diagrammatic scheme of circulation in a symmetrically constituted ocean.*

After G. Wüst.

The surface circulation of the Indian Ocean is influenced by the monsoon winds. The South Equatorial Current is distinct throughout the year; the Equatorial Counter Current during the Northeast Monsoon lies between 10° south and the equator but during the Southwest Monsoon it is obscured; there is a North Equatorial Current, really a westward monsoon drift, during the Northeast Monsoon, but during the Southwest Monsoon the direction of the surface drift is reversed.

Theoretically there are three regions of downsinking of water in each hemisphere in a symmetrical ocean (Wüst, 1930). There are on each side of the equator (1) A Subtropical Convergence in latitude approximately 30°, where there is downsinking of warm water of high salinity; (2) a Polar Front in latitude approximately 45° to 50°, where there is downsinking of cold water of rather high salinity; (3) the polar regions, latitude 60° +, where there is downsinking of cold polar water of rather low salinity—this is the water that forms the bottom water of the great ocean basins. In the West Atlantic Trough, according to Wüst, bottom water of Antarctic origin influences the bottom temperatures as far north as latitude 40° N.

"The last traces of Antarctic water, according to the distribution of bottom temperature, are recognized in approximately 40° north latitude" (Wüst, 1933, p. 36).

The special conditions in the large marginal seas connected with the ocean basins by straits deserve brief consideration. In seas such as the Baltic, where precipitation exceeds evaporation, there is inflow of ocean water of high salinity at the bottom and outflow of water of low salinity on the surface. In seas such as the Mediterranean and the Red Sea, where evaporation exceeds precipitation, there is inflow of normal ocean water on the surface and outflow of denser water at the bottom.

TEMPERATURE OF THE OCEAN

The movements of ocean waters, the major features of which have been indicated, largely control the distribution of temperature and other properties of sea water—but it should be remarked that temperature and salinity, the chief factors in determining the density of sea water, influence the movements of the water. The heat on the earth is derived from the sun, but this heat does not reach each unit area in equal amounts. There is greater heating in the tropical and subtropical regions than in the regions nearer the poles. Furthermore, because of the inclination of the earth's axis to the plane of the Ecliptic, there are the alternating seasons of summer and winter in temperate and polar latitudes. In low latitudes the temperatures are high, and the surface waters are warm; in the polar regions they are cold. Between the polar regions and the tropics, in the temperate zone, there is wide variation in the surface temperature of the ocean. Sir John Murray (1897) aptly expressed this zonation of the sea surface. He divided the surface of the oceans into five zones, as follows: (1) Two polar zones, one around each pole, in which the annual range of the surface temperature of the water does not exceed 10° F. (5.5° C.); (2) a tropical zone, in which the annual temperature range also does not exceed 10° F. (5.5° C.); (3) on each side of the tropical zone, between it and the polar zone, there is a temperate zone in which the temperature range exceeds 10° F. (5.5° C.) and may be as much as 40° or even 50° F. (22.2° to 27.7° C.).

This temperature distribution does not closely follow the parallels of latitude. Because of the scheme of circulation of the surface waters of the oceans, already outlined, warm water is carried poleward off the east sides of the continents. Consequently reef corals live in the coastal water of Japan as far north as Tateyama Wan, province of Awa, Lat. 34°57′ N. (Yabe and Sugiyama, 1932); and a restricted fauna of reef corals flourishes in the Bermuda Islands in about lat. 32° N. While warm water is carried poleward on the west sides of the oceans, cool water is carried equatorward on their east sides. Schott (1926; 1935) has given excellent discussions of the distribution of the surface temperatures in the major ocean basins. The general thermal contrast between the waters of the

west and east halves of the Pacific Ocean holds almost everywhere between 30° N. and 30° S. At Hongkong, near the tropic of Cancer, the temperature is 25° C.; at Cape San Lucas, Lower California, it is 20° C. On the equator the temperature in the west exceeds 29° C.; in the east it is below 25° C. Under the tropic of Capricorn, it is 22°-23° C. on the coast of Queensland, while it is 16°-17° C. on the coast of northern Chile. The temperature contrasts on the two sides of the Atlantic are similar to those in the Pacific. It has been mentioned that there is lowering of surface temperatures along the coasts of western Africa, California, and Peru because of the upwelling of water from deeper levels.

It has also been stated that cold water sinks below the surface water in both the polar regions and at the polar fronts. The bottom water in the great ocean basins is of polar origin, and most of it comes from the Antarctic region. In the polar regions the water temperature in places is as low as —1.9° C., the freezing point of the water there. Between the belts of the very cold water near the poles and the equator, the temperature in general decreases with depth. The range in temperature of the deep water in the Pacific is between 1° and 3° C. The range on the surface is between —1.9° and 30° C.; this is for the range in latitude from the margin of the Antarctic continent to the equator. The DANA during July 1929 measured a vertical section in lat. 40° N., long. 138° W. At the surface the temperature was 28.4° C.; at a depth of 3500 meters it was 1.60° C. The drop in temperature was 26.8° C. within a vertical distance of 3.5 kilometers.

The definition of temperature zones in the sea is difficult because of intergradations from one zone to another and the great fluctuations in temperature in the zones between the tropics and the polar regions. Murray recognized five zones, and James Johnstone adopted the same treatment of the subject. It is here tentatively proposed to recognize nine zones, four of which are paired, being represented in each hemisphere. They are as follows:

1-2. Two polar zones, a north and a south polar zone, with temperature limits of —1.9° and +5° C.

3-4. Two subpolar zones, one zone in each hemisphere, with temperature limits of +5° and +10° C. Along shore the water may freeze.

5-6. Two temperate zones, one in the northern, the other in the southern hemisphere. The lower temperature limit offshore may be put down as 10° C., but at the shore it may be as low as 0° C. or even slightly lower. The upper limit during the summer may be as high as 25° C. In a lagoon at Long Beach, California, the range is from 6.54° C. in January 1933 to 24.44° C. in August 1931.

7-8. Two subtropical zones, a northern and a southern, temperature minimum about 15° C., maximum during the summer 30° to 33° C.

9. One tropical zone, with the temperature range between 25° and usually 30° to 31° as a maximum, but in shallow water near shore it may exceed 31° C. and even reach 36° C.

In deep water within the tropics all five of the temperature zones between the tropics and the polar regions of one hemisphere are encountered between the surface and the bottom.

LIGHT

Two generally known facts are that the life of plants depends upon light and that plants are the basic food supply of animals. In the sea plants can live only above the light floor, the position of which is determined by the depth of penetration of light into the ocean water. Fleming and Revelle (1939) have recently given a good synoptic discussion of this subject.

Of the light that impinges on the sea surface, more is reflected back in high than in low latitudes, and the rays that penetrate the surface are deflected at a greater angle from the vertical in higher than in lower latitudes. The transmissive exponents (which are negative exponents) vary for the different wave lengths, being smaller for blue and green than for violet and red, with the result that blue and green penetrate to the maximum depths. The depth of penetration is also dependent on the amount of organic and inorganic matter suspended in the water. At Woods Hole, there is 1 per cent of blue light at 9 meters; in the Sargasso Sea there is 1 per cent at 148 meters. The most transparent ocean water known is in the Sargasso Sea. On the continental shelves where there is considerable or much suspended matter, the depth of penetration ranges from a few meters to 50 or more meters. The depth is not constant for the same place.

CHEMICAL FEATURES OF SEA WATER

Salinity.—Both solids and gases are dissolved in sea water. Brief attention will first be paid to the solids. For fuller discussion reference is made to the paper by Fleming and Revelle (1939) already mentioned. First, the term salinity will be defined, quoting from Knudsen and Sörensen. It is:

"The total amount of solid material contained in one kilogram of sea water when all of the carbonates have been converted into oxides, the bromine and iodine replaced by chlorine, and all the organic matter completely oxidised."

Salinity does not precisely represent the actual concentration of dissolved solids in sea water but it is a conventionalized representation of the concentration. Salinity is given as parts per thousand by weight and it is

expressed by the symbol $^{o}/_{oo}$. The composition of the solids in sea water of salinity $35^{o}/_{oo}$ is given in Table 2 (Fleming and Revelle, 1939).

In sea water Cl + Na = 55.29 + 30.59 = 85.88 per cent by weight of the solids in solution. In the open ocean the salinity ranges from about

TABLE 2.—*Solids in sea water*

Ion	Gm./kg. of sea water	Ionic conc./kg. sea water
Cl'	19.34	0.545
SO_4''	2.70	0.028
HCO_3'	0.15	0.002
Br'	0.07	0.001
Na^+	10.72	0.466
Mg^{++}	1.30	0.053
Ca^{++}	0.42	0.011
K^+	0.38	0.010
	35.08	1.116

$30^{o}/_{oo}$ to about $38^{o}/_{oo}$. The water of highest salinity is in the Sargasso Sea. In general low salinities, $30^{o}/_{oo}$ to $33^{o}/_{oo}$, occur in the polar and subpolar regions and near continents. The average for all oceans is about $35^{o}/_{oo}$. In marginal seas where precipitation is heavy, the salinity may be very low, $7^{o}/_{oo}$ in parts of the Baltic; but in marginal seas where evaporations exceeds precipitation the salinity may be high, 38 to $39^{o}/_{oo}$ in the Mediterranean and it may exceed $40^{o}/_{oo}$ in the Red Sea.

For the open ocean the ranges in salinity do not appear to be of biological significance, but near shore where there is flooding by fresh water from land areas or where there is merging of ocean-water salinities into those of brackish water the salinity is a factor in determining the kinds of organisms that live there.

Plant nutrients.—There are several solids that are present in small amounts in sea water, which vary greatly in concentration, but which are essential for the life of plants. The most noteworthy of these are the compounds of phosphorus, nitrogen, and silicon. Phosphates and nitrogen compounds are prime necessities as plant food—they are limiting factors. Silica is required by diatoms and Radiolaria for the construction of their tests. The distribution of these substances in the sea has received much attention, and there is much information on phosphates and nitrogen compounds, but it cannot be summarized in this connection. The data on silica are inadequate.

Since the surface layers of the ocean, after a vigorous growth of phytoplankton, are depleted of their stock of plant nutrients, a note will be made on how the supplies are replenished. Before presenting the explana-

tions it will be said that organisms living at and near the surface of the sea die and their remains fall to lower levels where there are no plants to consume plant food. Consequently there is an accumulation of plant nutrients below the light floor. There are two mechanisms whereby the

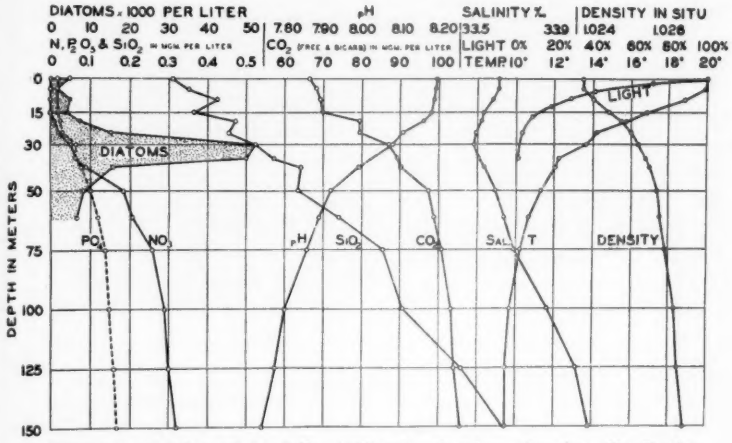

FIGURE 3.—*Section off La Jolla, California, showing subsurface distribution of solutes.*

After E. G. Moberg.

stores of nutrients are brought back to the surface. In high latitudes winter cooling causes the depleted surface water to sink, and warmer water from lower levels rises to the surface. In other words because of temperature changes the water columns are overturned. This phenomenon is exemplified along and near the coast of England. The other mechanism is the upwelling which has already been mentioned as occurring along the coastal regions of California, Peru, and West Africa. Another means of supplying plant food to the sea is the runoff of fresh water from the land.

Oxygen.—The only gas dissolved in sea water that will be considered is oxygen. In general the oxygen in sea water at the surface is in equilibrium with the air, while a short distance below the surface but above the light floor, because of the activity of plants, the water may be supersaturated. All the oxygen in the ocean comes either from the atmosphere or from the photosynthetic activities of plants. The oxygen below the light floor has been carried to lower levels by water that has sunk from or from near the surface, and its general distribution in the ocean is due to the circulation of the ocean waters.

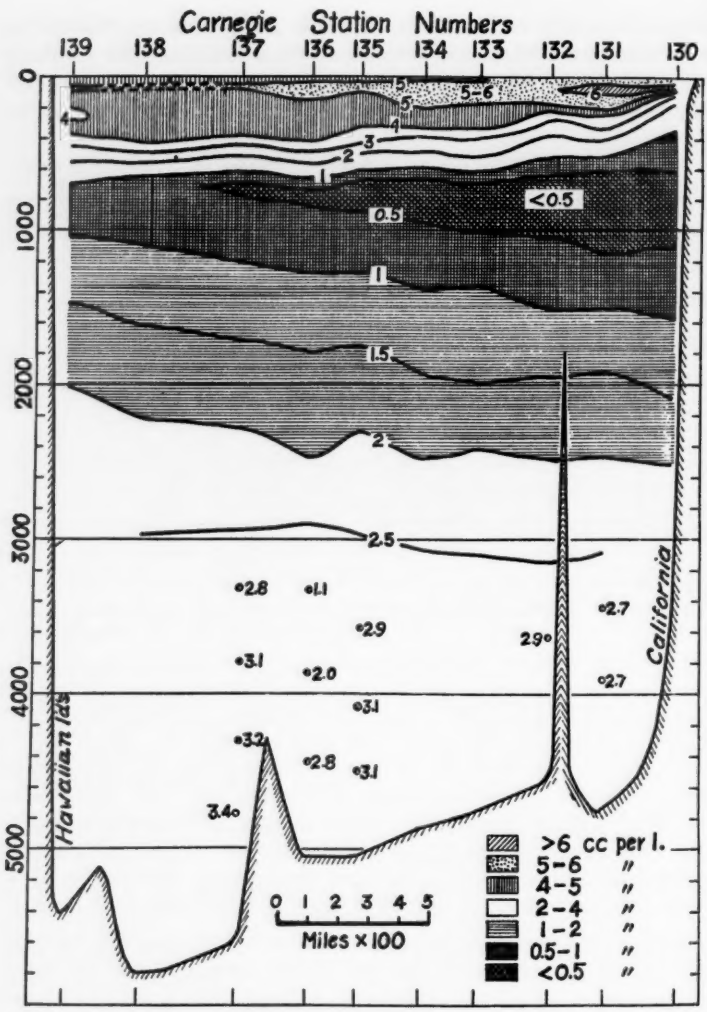

FIGURE 4.—*Section, San Francisco to Honolulu, showing distribution of oxygen, cc/l.*

After E. G. Moberg, "Carnegie" data.

The quantity of oxygen in the subsurface waters of the ocean varies greatly. There is more in the Atlantic than in the Pacific Ocean. In each ocean there is a minimum-oxygen layer a few hundred meters below the

surface. The depth and character of this layer is illustrated by a graph and will not be described (Moberg, 1930). In the open ocean there is sufficient oxygen in the bottom water to support animal life, but in basins where the circulation of the bottom water is obstructed, as in fiords at the mouths of which there are sills, and in the Black Sea, there is no available oxygen, but there is hydrogen sulphide in the water at lower levels and in the bottom muds.

SURFACE OF THE BOTTOM

Sea bottom on which deposition is not taking place is areally of minor extent but such bottom does exist in each of the great oceans. Where currents are strong, as between the Florida Keys, the bottom is swept clean of all sediment. Areas without sediments have been reported from the North Atlantic by Murray (1912) and others, and from off Providence Island, between the Seychelles Islands and Madagascar, by Stanley Gardiner and Forster Cooper (1907, p. 147). Other areas of nondeposition are known off both the Atlantic and Pacific coasts of the United States, especially in the walls of submarine canyons. Usually, however, the bottom is formed by some kind of sediment. No general account of marine sediments is possible in this connection. Attention is called to the volume entitled *Recent marine sediments*, just published by the American Association of Petroleum Geologists, under the editorship of Parker D. Trask (1939).

A rough classification of kinds of bottom material with reference to the habitats of organisms is as follows:

Littoral and neritic
- Rock
- Boulders, cobbles, pebbles
- Sand of several grades, coarse to fine
- Silt
- Clay

The chemical composition, especially of the sands, silt, and clay must be considered.

Deep-sea
- Terrigenous blue and green muds
- Organic oozes, Globigerina, pteropod, radiolarian, diatom
- Red clay

Brief remarks have been made on some, but not all, of those aspects of the sea that must be considered in studying in an empirical way the relations of marine organisms to their environment. These aspects are (1) depth and bottom configuration; (2) oceanic circulation; (3) temperature; (4) light; (5) chemical features, including salinity, plant nutrients,

and oxygen; and (6) surface of the bottom. For elaboration of these topics the literature on oceanography must be consulted. Two pertinent recent publications are the volume *Recent marine sediments,* already mentioned, and the two symposia *Conditions of existence of aquatic animals*

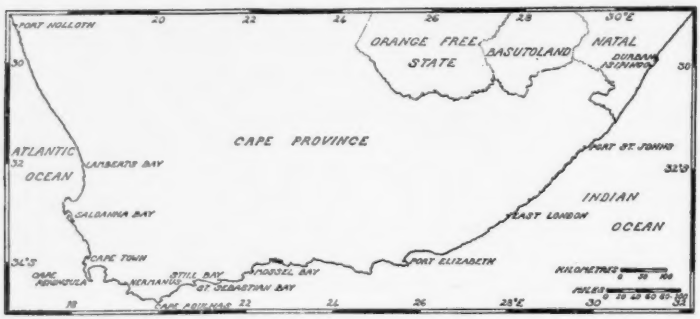

FIGURE 5.—*Map of southern end of South Africa.*

After T. A. Stephenson.

and *Oceanography,* edited by A. S. Pearse and published in Ecological Monographs (1934, vol. 4, no. 4.)

A FEW EXAMPLES OF PERTINENT ECOLOGICAL RESEARCHES

THE TIDAL ZONE OF SOUTH AFRICA BY T. A. STEPHENSON AND HIS ASSOCIATES

In October 1937 Dr. T. A. Stephenson, Professor of Zoology at the University of Cape Town, in collaboration with colleagues and students, began publishing a series of papers entitled *Papers on the ecology of the South African coast.* Nine numbers so far have been published either by the Royal Society of South Africa or the Natal Museum, and one article has appeared in the Linnaean Society's Journal—Zoology. Of these ten articles eight deal with the South African intertidal zone and its relation to ocean currents. (In list of references to literature *see* Bright, Eyre, and Stephenson.)

The marine conditions along and off the shore of South Africa are of unusual interest because there two kinds of water come into juxtaposition. On the east side from Durban southward there is the warm water of the Mozambique and Agulhas currents, while on the Atlantic west side the South Atlantic cold Antarctic intermediate water upwells. Cape Peninsula is near the meeting places of the warm and cold water, but the position of the contact shifts with season and weather.

Figure 5 shows the positions of the principal places at which investigations were made, except that Oudekraal, which is on the west side of Cape Peninsula, south of Cape Town, and St. James, which is at the base of the Peninsula on its east side, are not shown. The mean annual

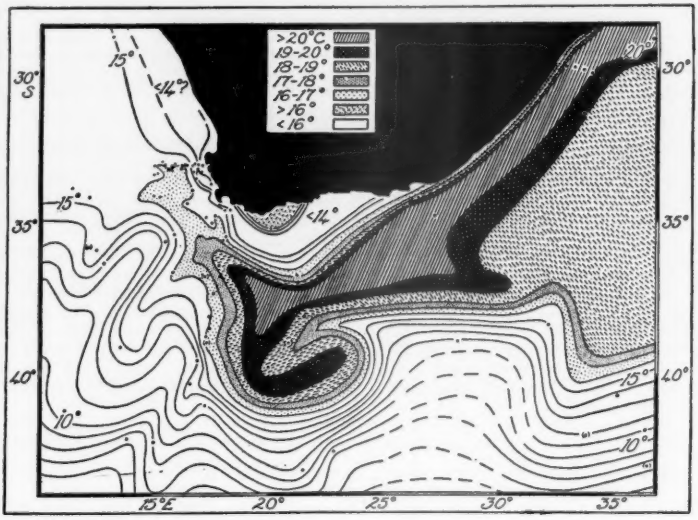

FIGURE 6.—*Temperatures at 50 meters off South Africa.*

After G. Dietrich.

temperature (°C.) after W. E. Isaac are as follows (T. A. Stephenson, 1939):

West Coast	South Coast	East Coast
Walvis Bay 16.1°	Simon's Bay 15.3°	East London 17.6°
Soldanha Bay 14.8°	Muizenberg 16.6°	Port St. Johns 19.3°
Dassen Island 13.45°	Hermanus 14.6°	Durban 21.8°
Robben Island 14.2°	Danger Point 15.6°	
Cape Town Pier 12.8°	Cape Agulhas 17.7°	
	Struys Bay 17.4°	
	Knysna Heads 16.8°	
	Cape St. Francis 17.25°	
	Bird Island 18.2°	

Stephenson remarks that for the interpretation of the exact significance of the figures Isaac's paper should be consulted. Figure 6 indicates the temperature distribution at 50 meters.

Stephenson does not give the salinity of the water for the region considered. According to Schott (1935) the range is from 35.4 to 35.5‰.

With reference to the vertical zonation, Stephenson says:

"Wherever the coast-line has been visited, from Port Nolloth in the west to Durban in the east, it has been possible to distinguish three principal zones, to which we have given the following names (arranged in order from above downward).

Littorina zone.
Balanoid zone.
Sublittoral fringe.

"In addition to these three, there exists along the greater part of the coast a distinct belt linking the sublittoral fringe with the Balanoid zone, and inhabited by a particularly dense population of limpets, the predominating species being *Patella argenvillei* in the northern part of the west coast and *P. cochlear* on the south coast. This zone has been called the Argenvillei zone or the Cochlear zone, according to which species is locally prevalent."

Horizontally three principal populations are recognized as follows:

"(1) A population of cold-loving organisms, which inhabit the west coast and extends in full force not farther south than the Cape of Good Hope, although many of its constituent species pass that point onto the south coast, along which they are to be found for a greater or lesser distance.

"(2) A series of organisms which flourish in warm-temperate conditions, and which are characteristic of the south coast. Many of members of this series continue onto one or both of the other coasts, some for shorter and others for longer distances.

"(3) A population of tropical species which is strongly represented in the Durban district (mixed with south-coast forms), but which disappears, apart from isolated species, between Durban and East London. Certain tropical species continue along the south coast, but the impressive assemblage of them found near Durban has disappeared. The population of the southern part of the east coast is similar to that of the south coast."

The sublittoral region of the shore on the west coast is dominated by laminarians. On the south and east coasts, where the water is warmer, there is usually no Laminarian zone. For each locality and each zone systematic lists of the organisms present are being prepared. Laboratory experiments on the reactions of specific organisms, including their eggs and larvae, to different temperatures, and analyses of the sea water for substances of biological significance are planned.

This series of studies is one of great value to geologists, for the different environments are characterized, and the organisms are considered with reference to those environments.

There are other properly conducted studies of the intertidal zone, but they cannot be reviewed here.

FORAMINIFERA

Four studies will be specifically discussed and others will be mentioned.

Ecologic relations of some Foraminifera by Richard D. Norton (1930). Norton studied samples from the Floridian, Bahamian, and Caribbean regions, the western Atlantic, off the west coast of South America, and Murray Island, Australia. He divided the stations into bathymetric zones depending on depth and temperature as follows:

"Zone A. Beach-5 fathoms, samples 1, 2, 3, 4, 5.
Temperature range less than 21.5°-31.4° C.

"Zone B. 5-60 fathoms, samples 6, 7, 8, 9.
Temperature range 18.9°-24.8° C.
"Zone C. 500-825 fathoms, samples 10, 11, 12, 13.
Temperature range 4°-7.61° C.
"Zone D. 2000-2850 fathoms, samples 14, 15.
Temperature range 1.83°-2.0° C.
"Zones A. and B. are termed shallow water, Zone C intermediate depths, and Zone D, deep water."

The bottom temperature for sample no. 11 is 4.44° C., depth 687 fathoms; and for nos. 12 and 13, Tongue of the Ocean, depth 800-825 fathoms, it is 4° C. These zones by very slight modification may be brought into conformity with the scheme of temperature zonation already suggested:

Subtropical, temperature 18.9°-31.4° C., depths beach to 60 fathoms
Subpolar, temperature 4.0°-7.61° C., depth 500-825 fathoms
Polar, temperature 1.83°-2.0° C., depths 2000-2850 fathoms

The bathymetric and thermal distribution of each species, genus, and family is presented in lists, tables, and graphs. Two graphs show some of the results. Norton in his conclusions says:

"In the very shallow-water Zone A, from 0-5 fathoms, where the temperature range is between 21° and 32° C., the Miliolidae and Peneroplidae are generally common to abundant. In certain restricted areas, the Valvulinidae, Calcarinidae, Homotremidae, and Nonionidae are rather common.
"The next lower zone, B, from 5 to 60 fathoms, temperature range 20° to 31° C., a marked decrease in the Peneroplidae and Miliolidae both in number of species and in individuals is noted. The Lagenidae, Textulariidae, Buliminidae, and Amphisteginidae are often common at these depths.
"In Zones C and D, from 2000-2850 fathoms, in temperatures from 2°-8° C., families of Globigerinidae and Globorotaliidae are predominant. The Lagenidae and Buliminidae persist to great depths but usually in small numbers. The Rotaliidae and Anomalinidae are rather uniformly present at nearly all depths and, as families, do not seem to possess definite ecologic value."

The mixture of shallow-water with deep-water species in samples 12 and 13, both Tongue of the Ocean, depth 800-825 fathoms, deserves notice. Transportation by currents from shallow water or by winds from beaches is the most reasonable explanation. The samples are death assemblages of incongruous elements.

Temperature- and depth-distribution of some Recent and fossil Foraminifera in the southern California region by Manley L. Natland (1933). Natland collected a series of samples at 153 stations along a line from Long Beach to Catalina Island. At each station the bottom temperature was determined, a sample of water was taken for salinity, and a sample of the bottom was collected for sedimentary analysis. Since the salinity varied only slightly it was not reported; it was about 34‰. Twelve samples from deeper water were obtained from collections made by Parker D. Trask and the Coast and Geodetic Survey.

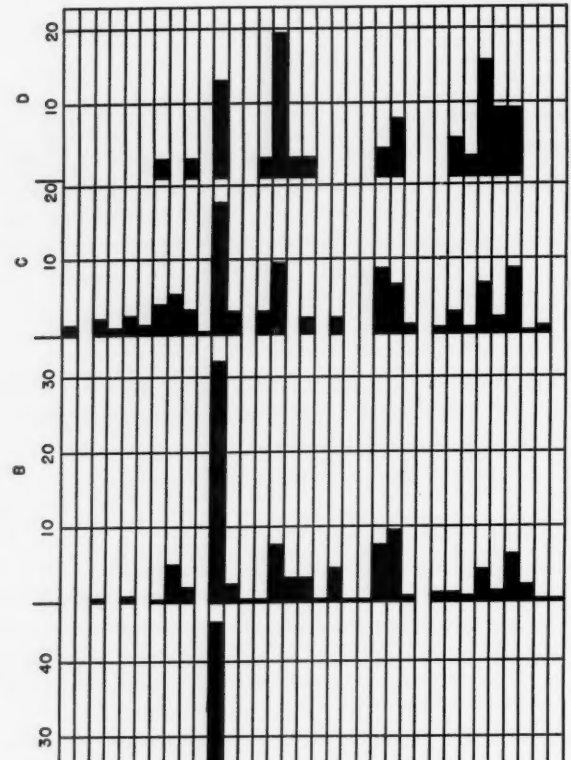

FIGURE 7.—*Percentage of species in families of Foraminifera according to temperature-depth zones.*

After R. D. Norton.

Natland recognized five temperature-depth zones as follows:

"Zone I. Shallow, brackish water lagoon
Depth at low tide, 1 foot; at high tide 4 to 7 feet
Temperature of water, August, 1931, at low tide, 24.4° C.
Temperature of the air at the same time, 3:00 P. M., 28.33° C.
Temperature of water, January, 1933, at low tide, 7:30 A. M., 6.54° C.
Temperature of air at the same time, 5.66° C.
Abundant: *Rotalia beccarii* (Linnaeus)

"Zone II. Bottom temperature range, 21.43° C.-13.20° C.
Depth range, 14 feet-125 feet (open ocean).
Abundant: *Nonion scapha* (Fichtel and Moll)
Elphidium articulatum (d'Orbigny)?
hannai Cushman and Grant
hughesi Cushman and Grant
spinatum Cushman and Valentine
Buliminella elongatissima (d'Orbigny)
Eponides ornata (d'Orbigny)

"Zone III. Bottom temperature, range 13.20° C.-8.50° C.
Depth range, 125-900 feet
Abundant: *Cassidulina californica* Cushman and Hughes
limbata Cushman and Hughes
tortuosa Cushman and Hughes
Eponides repanda (Fichtel and Moll)
Polymorphina charlottensis Cushman
Quinqueloculina akneriana d'Orbigny
Robertina charlottensis (Cushman)
Sigmomorphina frondicula riformis (Galloway and Wissler)
Triloculina trigonula (Lamerck)

"Zone IV. Bottom temperature range, 8.50° C.- ± 4° C.
Depth range, 900 feet- ± 6,500 feet
Abundant: *Bolivina subadvena* v. *spissa* Cushman
argentea Cushman
Cassidulina cushmani Stewart and Stewart
Globobulimina pacifica Cushman
Pulvinulinella pacifica Cushman
Uvigerina peregrina Cushman

"Zone V. Bottom temperature range, ± 4.° C.- ± 2.40° C.
Depth range, 6.500 feet- ± 8,340 feet
Abundant: *Bulimina rostrata* H. B. Brady
Pullenia bulloides (d'Orbigny)
Nonion umbilicatula (Montagu) v. *pacifica* Cushman."

In his discussion of the relations of the faunas to depth and temperature, Natland says:

". . . The temperature gradient is steepest from the surface down to 1000 feet, but below 1000 feet the gradient is very gentle. In the shallower depths where the temperature declines rapidly there is a corresponding rapid change in the foraminiferal fauna, while in the deeper part of the channel where the temperature changes are very slight, even with an increase in depth of several thousand feet the changes in the foraminiferal fauna are much slower. Thus it would seem that temperature has a far greater influence than depth on some foraminifera."

Natland considers in his paper samples from Hall Canyon, from beds thought to range in age from lower Pliocene to Pleistocene, and correlates the fossiliferous zones with the zones recognized in the sea along and off the shore of southern California. The closing paragraph reads as follows:

"The work here detailed has shown that on the present sea floor, which may some day be a fossil horizon in a sedimentary section, like that exposed in Hall Canyon,

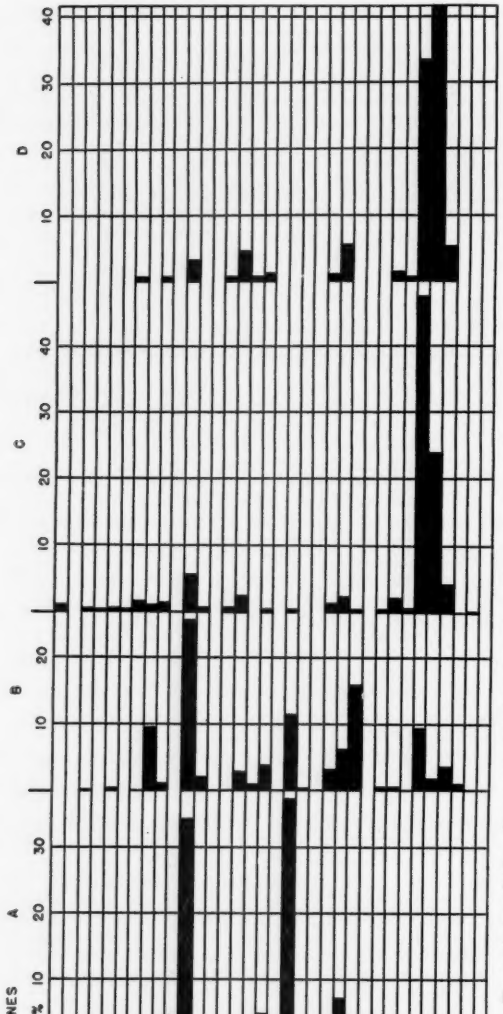

FIGURE 8.—*Percentage of abundance of individuals in families of Foraminifera according to temperature-depth zones.*

After R. D. Norton.

there are five distinct faunal assemblages in close proximity. Therefore dissimilar faunas may be contemporaneous and, conversely, the correlation of two widely separated outcrops based on similarity of their foraminiferal assemblages alone is apt to be erroneous. The resemblance of two assemblages indicates similar environments but not necessarily contemporaneity."

The temperature zones of Natland can be arranged to conform to those suggested in this address:

Zones I and II, are temperate, temperatures from a minimum of 6.54° to a maximum of 24.4° C. at the shore; range not so great away from the shore.
Zone III, crosses the temperature boundary between cold temperate and subpolar, range 13.20° to 8.50° C.
Zone IV, subpolar, range 8.50° to ± 4.0° C.
Zone V, polar, range ± 4° C. to ± 2.40° C.

These studies of Norton and Natland are the only ones known to me in which deliberate attempts have been made to discover among foraminiferal faunas definite temperature zonation. There are bodies of information that have not been utilized. Those systematic papers in which localities, depths, and bottom temperatures are given can be made the basis of ecological studies. Other studies of Recent Foraminifera, such as those of life histories and the ecology of single species by Myers and of the food of Protozoa by Sandon, have yielded results of significance. Other important researches cannot at present even be mentioned.

Miocene stratigraphy of California by Robert M. Kleinpell.—Although the studies of the ecology of living foraminiferal faunas will not be further discussed here, attention will be called to two studies of fossil faunas. The first is Kleinpell's *Miocene stratigraphy of California* (1938). Pages 11-19 are devoted to the "Ecology of the Reliz Canyon Foraminifera". After giving a considerable list of publications on modern Foraminifera Kleinpell says (p. 13):

"More data are available on bathymetric occurrence than on temperature, degree of salinity of the water, aeration, pressure, light, associated fauna and flora, et cetera. This is unfortunate, for the distribution of Foraminifera is perhaps affected more by temperature than by depth."

The "perhaps" might have been omitted. With the possible exception of forms that contain zooxanthellae, it is doubtful if depth is an important factor, and, in those forms, it is the diminution or elimination of light because of depth that is effective.

Kleinpell says (p. 14) that all the forms considered have been recorded from temperatures of 38° F. or colder. According to the zonal classification here suggested 38° F. (3.3° C.) is a polar temperature. In general the fauna is considered to be a temperate-zone fauna, probably ranging in depth from 25 to 500 fathoms. This review of Kleinpell's book will be closed with the remark that the conclusions in it are expressed as tentative. The work represents the kind of endeavor that is greatly needed. May we get more of the same kind!

Biogeographic relations of the orbitoid Foraminifera by T. W. Vaughan (1933).—The other paper that I wish to mention is one by myself, in which an endeavor was made to consider the organisms with reference to depth, temperature, ocean currents, and barriers, both land and tem-

TABLE 3.—*Depth distribution of the Recent genera*

Exclusively shallow water	9
Shallow water to 50 fathoms	1
Shallow water to 150 fathoms	1
Shallow water to 315 fathoms	1
Shallow water to 400 fathoms	1
Shallow water to 750 fathoms	2
Shallow water to 1500 fathoms	2
From 38 to 300 fathoms	1
From 50 to 300 fathoms	1
From 100 to 220 fathoms	1
From 100 to 750 fathoms	1
From 158 to 892 fathoms	1
Data deficient concerning	2
Total	24

perature. The orbitoids are shallow water, less than 180 meters, tropical or subtropical organisms, minimum temperature about 15° C., slightly lower is possible. Their stratigraphic range is from Upper Cretaceous to lower Miocene.

STONY HEXACORALS

The discussion of this topic must be briefer than I wished. It will be introduced by a table taken from my monograph entitled *The Eocene and Lower Oligocene coral faunas of the United States* (1900).

Succeeding this table is a discussion of the probable depth of the coral fauna in each formation. At the time this paper was written, now 40 years ago, temperature data were not available for the different genera. Now inferences as to the probable temperatures could be added.

A few years later I was requested by Dr. C. H. Gilbert to prepare a report on the corals collected in the vicinity of the Hawaiian Islands by the U. S. Bureau of Fisheries steamer ALBATROSS in 1902. The report was published in 1907. In this paper the different species of corals were studied with reference to depth, temperature, and character of the bottom. Tables 4-6 (Vaughan, 1919) are as shown in Tables 4 and 5.

Regarding the distribution according to temperature, five zones are represented:

Tropical, temperature, 25.6° to 22.8° C.
Subtropical, temperature 22.8° to 15.6° C.
Temperate, 15.6° to 10° C.
Subpolar, 10° to 4.5° C.
Polar, 4.5° to 1.12° C.

TABLE 4.—*Bathymetric distribution of corals in the Hawaiian Islands*—
Showing the numerical distribution of forms according to depth.

Depth in meters	0–46	46–74	74–183	183–366	366–549	549–732	732–915	915–1098	1098–1281	1281–1464	1464–1647	1647–2105
Number of forms found at that depth	77	14	7	21	13	8	0	0	1	0	2	1
Number of forms confined to that depth	70	5	2	14	6	5	.....	.....	0	0	1	1
Number of forms ranging into the next deeper	7	2	4	5	3	0	.....	.....	0	0	0	.....
Number of forms occurring in next shallower	.....	7	2	4	5	3	.....	.....	0	.....	0	.....
Number of forms occurring in both shallower and deeper water	.....	0	1	2	1	0	.....	.....	.....	.....	.....	.....

TABLE 5.—*Bathymetric distribution of coral genera in the Hawaiian Islands*

(Depths in meters)

0–46	46–74	74–183	183–366	366–549	549–762	732–915	915–1098	1098–1281	1281–1464	1464–1647	1647–2105
Pocillopora *Leptastrea* *Cyphastrea* *Coelastrea* *Fungia* *Pavona* *Leptoseris* *Stephanaria* *Psammocora* *Dendrophyllia* *Montipora* *Porites* *Alveopora*	*Pocillopora* *Pavona* *Leptoseris* *Montipora* *Porites*	*Madracis* *Fungia* *Leptoseris* *Stephanophyllia* *Balanophyllia*	*Flabellium* *Placotrochus* *Paracyathus* *Deltocyathus* *Caryophyllia* *Cyathoceras* *Anthemiphyllia* *Madracis* *Leptoseris* *Stephanophyllia* *Endopachys* *Balanophyllia* *Dendrophyllia*	*Flabellum* *Gardineria* *Desmophyllum* *Paracyathus* *Trochocyathus* *Caryophyllia* *Cyathoceras* *Madracis* *Leptoseris* *Anisopsammia*	*Desmophyllum* *Caryophyllia* *Cyathoceras* *Ceratotrochus* *Madrepora* *Mussa?* *Anisopsammia*	None	None	*Flabellum*	None	*Flabellum* *Caryophyllia*	*Bathyactis*
13	5	5	13	10	7	0	0	1	0	2	1
Total number of genera											

According to the records available for the report, the range in temperature on the Hawaiian reefs between March 27 and August 29, 1902, was from 22.8° to 26.4° C. The bottom temperature reported as 1.12° C. is probably somewhat too low.

TABLE 6.—*Distribution of genera of corals according to temperature in the Hawaiian Islands.*

25.6° to 22.8° C.	22.8° to 15.6° C.	15.6° to 10° C.	10° to 4.5° C.	4.5° to 1.12° C.
Pocillopora	*Flabellum* [1]	*Flabellum*	*Flabellum*	*Flabellum*
Leptastrea	*Placotrochus* [1]	*Cyathoceras*	*Gardineria*	*Caryophyllia*
Cyphastrea	*Paracyathus* [1]	*Madracis*	*Desmophyllum*	*Bathyactis*
Coelastrea	*Caryophyllia* [1]	*Stephanophyllia*	*Paracyathus*	
Fungia	*Cyathoceras* [1]	*Balanophyllia*	*Deltocyathus*	
Pavona	*Anthemiphyllia* [1]		*Trochocyathus*	
Leptoseris	*Madracis* [1]		*Caryophyllia*	
Stephanaria	*Fungia* [2]		*Cyathoceras*	
Psammocora	*Leptoseris*		*Ceratotrochus*	
Dendrophyllia	*Stephanophyllia* [1]		*Madrepora*	
Montipora	*Balanophyllia* [3]		*Madracis*	
Porites	*Dendrophyllia* [1]		*Mussa?* sp. juv	
Alveopora			*Leptoseris*	
			Stephanophyllia	
			Endopachys	
			Balanophyllia	
			Dendrophyllia	
			Anisopsammia	
Total number of genera				
13	12	5	18	3

[1] Not obtained at a temperature so high as 21° C. (70° F.).
[2] Not obtained at a temperature so low as 21° C. (70° F.).
[3] Temperature range doubtful.

Between 1907 and 1918 I conducted extensive experimental investigations on corals at Tortugas, Florida, and Andros Island, Bahamas, and I wrote a large report on collections from Murray Island, Australia; Cocos-Keeling Islands, Indian Ocean; and Fanning Island in the tropical central Pacific (Vaughan, 1918). In these researches corals were studied with reference to (1) The nature of the movement of the water; (2) depth; (3) light; (4) temperature; (5) salinity; (6) sediment; (7) exposure to the air; and (8) food. Corals were reared from the time of the extrusion of the planulae until the attached colonies were 5 years of age. Extensive experiments and observations were made on growth rate on colonies both artificially planted and growing naturally in the sea.

The relations of corals to the movement of the surface water will be briefly considered. Tables 7 and 8 illustrate such relations.

The same species of branching coral may occur in both a rough water and a quiet water habitat and it adapts itself to its environment. In rough water the branches are short and stubby; in quiet water elongate and fragile.

TABLE 7.—*Relations of growth form of Cocos-Keeling corals to habitat*

Habitat	Free corals	Fragile branches or folia	Stout branches and lobate columns	Growth form massive
Lagoon	2	11	5	5
Barrier pools and barrier flat	2	6 (mostly on lagoon edge of flat)	4	8
Exposed side of barrier			3	13

From what has been said it is obvious that there are two major coral faunas living contemporaneously in the ocean. The first is the shallow-water fauna of the tropics and the subtropics which grades downward into a closely related fauna between 45 and 75 meters in depth and between 15° and 23° C. in temperature in tropical and subtropical regions. Within the shoal waters of the tropics there is differentiation into faunules according to position on the reef, tide pools, flats, and the outer declivity of the reef. Such faunules living within about half a mile of each other actually have in places from only 10 to 30 per cent of their species in common.

The great so-called deep-sea fauna occurs in the tropics at depths between 180 and 540 meters, with temperatures between 10° and 4.5° C. Some members of this fauna occur in water with slightly higher temperature, while a few extend into deeper water with truly polar temperatures. It is temperature rather than depth that controls the bathymetric distribution of all corals except the shallow-water forms that build reefs or are associated with reef builders in the tropics or subtropics.

Experimental studies have necessarily been confined to the shallow-water forms. The conditions for vigorous growth of the reef-forming corals are (1) depth of water not over 45 meters, usually less; (2) bottom firm; (3) water circulating, at times strongly agitated; (4) abundant oxygen; (5) an abundance of small animal plankton; (6) strong light; (7) temperature—annual minimum not below 18° C., minimum average temperature for the coldest month in the year not lower than 22° C.; (8) salinity between 27 and about 40 parts per thousand.

The data and conclusions regarding corals so far presented are mostly the results of my own studies, because those studies were planned and

TABLE 8.—*Relations of growth-form of corals to habitat*
Along line I across southeast reef, Murray Island, Australia.

Distance from shore (in feet)	Depth of water at low tide (in inches)	Character of bottom	Number of species at each station	Number of species according to growth form		
				Fragile branches and free disks	Stout branches	Massive or incrusting
300	2 – 4	Hard limestone mud over lava rock	1	.....	.....	1
400	4.5– 5	Firm limestone mud	7	3	.....	4
450–550	6 –12	Sand and mud, rock	10	3	.....	7
600–650	6.5–10	Sandy	18	7	.....	11
800–820	10 –11	Broken coral	20	6	1	12
1000–1020	14 –17	Rocky	21	10	1	10
1200–1250	12 –16	Rocky	18	6	2	10
1400–1445	14 –15	Rocky, broken coral	24	10	2	12
1600–1675	10 –16	Hard, rocky, broken coral	32	4	2	26
1720–1775	2.5– 3	Hard, rocky, with crevice like tide pools	13	.....	6	7

* *Acropora pectinata* (Brook), which is of discoid corymbose growth form, is not counted in the tabulation.

conducted to build a foundation for paleogeographic deductions. But I am not the only one during recent years to make studies of the ecology of corals. J. Stanley Gardiner, A. G. Mayor, C. Crossland, C. H. Edmondson, H. Boschma, J. H. F. Umbgrove, J. Verwey, C. M. Yonge, T. A. Stephenson, Miss S. M. Manton, and several Japanese investigators working under the direction of S. Hatai at the Palao Tropical Biological Station deserve mention. Space does not permit a review here of the results of these workers.

CONCLUSIONS

The subject selected for this address cannot be adequately treated in the time available for its presentation. The attempt to indicate some of the features of marine environments is necessarily sketchy, but it is hoped that the importance of knowing the physical and chemical characteristics of each of the different environmental complexes in the sea and of knowing the organisms associated with each complex has been made clear. The relations of organisms to environments has been treated in an entirely empirical way. Adaptation to environment is fundamentally a physiological matter, depending on complex physical and biochemical processes. The two symposia organized by A. S. Pearse (1934) bear on the investigation of the fundamentals and they are recommended to those who wish to look more deeply into that aspect of the subject. Geologists cannot reasonably be expected to be physiologists. They must content themselves with knowledge of empirical relations which usually must be explained by others. However, there is no cogent reason against geologists and physiologists becoming acquainted with each other.

Although it was said at the beginning of this lecture that emphasis would not be placed on the utilization of organic remains in solving problems of stratigraphic correlation, it was not intended to exclude completely from consideration that aspect of the subject. It will be recalled that every kind of environment indicated for the present ocean exists contemporaneously, that each kind of environment, if it will support life, has its own characteristic biologic assemblage, and that all these different assemblages are living at the same time. Biological difference does not necessarily mean difference in geological age. It may mean only difference in environment. Instances of such relations have been given for organisms of the intertidal zone, Foraminifera, and corals.

Conversely, rather close similarity between faunas may not mean identity in geological age. Numerous species have extended stratigraphic ranges. For instance, many species occurring in the present West Indian coral fauna already existed in Miocene deposits in that region, but in the

Miocene faunas there are both species and genera that are absent from the living fauna. Faunal similarity is perhaps even more indicative of ecologic than of age identity.

I am not arguing against the use of any group of organisms in stratigraphic investigations. What I am contending for is that dependence should not be placed solely on the identification of species for the determination of age identity or age difference in beds.

For knowledge of the paleogeography of the successive seas of the past it has already been said that we must first go to the seas of the present. Investigations of modern marine sediments, as shown by the volume recently edited by Trask (1939), have outstripped biological investigations needed for geological interpretation. The closing remarks of this address will be devoted to suggestions as to how at least some of the deficiencies may be supplied.

(1) Considerable bodies of spotty, scattered, unorganized information are available. For each group of marine organisms that has hard parts, specialists should try to bring together what is known with reference to the different environmental categories. Since the purpose of the project is to build premises for recognizing past environments, the different environmental categories should be defined and biologically characterized as comprehensively as possible. The leader in the enterprise must be an experienced stratigraphic geologist who is also biologically trained and who has broad familiarity with modern oceanography. The assistance of biologists will be necessary, but because very few of them have worked on problems of stratigraphy and paleogeography, they should be collaborators, not leaders.

(2) Additional investigations on organisms in the sea with reference to conditions in the sea are needed. Both groups of organisms with reference to environmental categories and the biological assemblages of the different environments need further study. Again these researches should be conducted by geologically trained persons. Because of its bearing on this suggestion a conversation that I heard between Sir John Murray and Professor Karl von Zittel during the international geological congress in Russia in 1897 will be recalled. They advocated the establishment of a floating oceanographic laboratory to which geologists might go and study marine phenomena of geological significance. Already Johannes Walther in 1883 and 1885 had utilized the Zoological Station at Naples for studies by him of the Mediterranean.

During recent years the number of marine stations, some of them with broad oceanographic programs, has greatly increased (Vaughan, 1937, p. 71-225). Some of these institutions include within the scope of their activities geological researches. This remark particularly applies in the

United States, to the Scripps Institution of Oceanography and the Woods Hole Oceanographic Institution. The facilities for geological investigations at these and other institutions are utilized by some but not by nearly enough geologists. Furthermore there should be closer affiliation than there is between the geological departments of the universities and these institutions.

(3) Since the investigations outlined have for their purpose supplying a basis for the interpretation of ancient faunas and floras, I shall close this address by saying that there should be unremitting attempts to make interpretations of the environments of ancient biological assemblages. The effort Schuchert made in the conference on *Criteria in Paleozoic paleogeography* he organized while president of the Paleontological Society and that of Twenhofel in the papers he brought together on paleoecology are valuable contributions along proper lines. There should be continuous shuttling from studies of the modern to studies of the ancient and back again from the ancient to the modern. By this process we may confidently expect to increase our understanding of much of the history of the earth.

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TERTIARY FORESTS AND CONTINENTAL HISTORY

BY RALPH W. CHANEY

(Address as retiring President of the Paleontological Society)

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INTRODUCTION

As students of the earth, we have looked largely to the sea for records of earth history. This predominant interest in an environment remote from our continental habitat has been forced upon us by the prevalence of marine deposits in regions where geology and paleontology have been most fully studied. As typically terrestrial members of the contemporary mammalian fauna, we might be expected to concern ourselves largely with the continents and land life of the past. But in most rocks, the record is not sufficiently complete to chronicle the events and populations above sea level. Not choice but necessity has dictated our dependence upon the sands of the sea to tell us the story of the earth.

Unlike much of the record of earlier eras, deposits of the Cenozoic permit us to extend our study of earth history far inland from ancient shores. Vulcanism during the Tertiary provided conditions favorable

to the accumulation of pyroclastic sediments in many valleys and lake basins of western America. While not so widely distributed as the glacial deposits of the Pleistocene, these beds of ash and tuff were better suited by texture and mode of deposition to preserve the remains of animals and plants. Concurrent lava flows have served as cappings which have protected them from erosion. Exposed in regions of sparse rainfall, many of the volcanic strata have as yet been only partially removed. They have not been mantled by glacial drift, nor extensively concealed by forests. We are living in the narrow interval in which terrestrial rocks of the immediate past are still preserved over wide areas, —at a time especially favorable for studying the continental record. In some places the sediments of Tertiary uplands may still be traced down across the strand-line to deposits containing marine organisms. From this relatively complete section, we have a basis not only for surveying the continental history of the Cenozoic, but for reconstructing the fragmentary record of terrestrial conditions during earlier eras.

Removal by streams and winds awaits the upland deposits of the Tertiary, perhaps within the epoch in which we are living. In the meantime leaves and fruits, imprinted upon these volcanic shales, tell us the nature and distribution of ancient forests. Petrified stems, lodged among the gravels of old channels, indicate trees no shorter in stature than our tallest redwoods. Paths of migration may be traced over routes which still control the distribution of living organisms,—along mountain chains which now as in the past have determined the climates upon their flanks. The contribution of these Tertiary plants to our knowledge of continental history will be the subject of my remarks on this occasion. Emphasis will be placed upon the record in western America, and northward around the Pacific Basin to China.

THE FACTOR OF DISTRIBUTION IN AGE DETERMINATION

In considering the contribution of paleobotany to our knowledge of Tertiary stratigraphy in western America, it is important to emphasize that the sequence of fossil floras has been rather completely worked out, although in some cases the exact age of the beds containing them is still undetermined. Relative age, rather than position in the standard section of a distant continent, seems in any case the more critical consideration. In western America, as elsewhere, we frequently disagree regarding the exact boundaries of the subdivisions of the Tertiary. The line of separation between the Eocene and Oligocene in Washington and Oregon has been placed at several horizons; difference of opinion exists as to whether the John Day beds of Oregon fall in the Oligocene or Miocene; vertebrate paleontologists who consider *Hipparion* an infallible indicator of the Plio-

cene place the Miocene-Pliocene boundary lower in the section than students of plants and invertebrates. Similar discrepancies in age reference are to be noted in recent work on the type sections of Europe. But there can be few important differences of opinion regarding floral and faunal sequence in western America, for fossil remains are abundantly distributed both geographically and stratigraphically. Where terrestrial plants occur in association with marine invertebrates, an effective means is provided for correlating the land-laid deposits of the interior with marine formations on the continental borders.

The John Day Basin provides the most complete Tertiary section of terrestrial deposits in western America (Merriam, 1901; Knowlton, 1902; Buwalda, 1927). Volcanic sediments were widely accumulated in this eastern Oregon area during most of the period, in contrast to their scattered occurrence in isolated basins at many other localities. The Clarno formation, an eruptive series with tufaceous lenses, is referred to the Eocene on the basis of its large-leafed evergreen plants. Similar subtropical floras have been recorded from the lower portion of the Tertiary section in western Oregon, on both sides of the Cascades in Washington, on the western slope of the Sierra Nevada in California, and eastward into the Rocky Mountains. The John Day formation is considered to cover the interval from Upper Oligocene to Lower Miocene as judged by the Bridge Creek flora and associated mammalian faunas. This temperate assemblage has been recorded from many other localities in western America and in Eurasia. The overlying Columbia River lavas contain no organic record in the John Day Basin, but intercalated sediments to the north include the Eagle Creek and Latah floras, of Middle Miocene age. Resting upon these basalt flows in many places are the lake deposits of the Mascall formation, which contain an Upper Miocene flora and fauna. Mascall plants are readily distinguishable from the Bridge Creek by their drier and warmer aspect. Related floras occur widely in the younger Miocene deposits of our western states and at many localities in Eurasia. The Rattlesnake formation of the John Day Basin, in common with many other continental deposits of the Pliocene, is not known to contain plant fossils. Recent studies, made in immediately adjacent areas with the assistance of a grant from the Penrose Fund of the Geological Society of America, are indicating relationships between certain floras above the Columbia River lavas and those referred to the Pliocene in California and Nevada. It is now possible to recognize floras from many isolated areas and incomplete sections in North America and eastern Asia, and to assign them to positions in the floral sequence on the basis of their relationship to the stratigraphic units of the John Day Basin.

In establishing this sequence of fossil floras, it is highly desirable to recognize in the plants themselves an independent developmental trend which may serve as a check for stratigraphic interpretations. The phylogenetic development of mammals offers ample corroborative data for conclusions based upon their occurrence in the rocks. Few such trends are shown by Tertiary plants, most of whose arborescent genera have survived without known change since the Eocene. Even the degree of speciation in subsequent time is so slight as to make evolutionary trends based upon plant fossils obscure or impossible to demonstrate at the present time. But while the majority of Tertiary trees have come down to the present with little change in their leaves, fruits and stems, differences in distribution are apparent from epoch to epoch, especially when forests rather than individual species are considered. These are interpreted as having developmental, and therefore time significance.

Miocene and Pliocene floras of California and Oregon are made up predominantly of genera still living in the United States; those of the earlier Oligocene and Eocene are now restricted largely to low latitudes. A change from subtropical to temperate climate is indicated in western America during the Tertiary, a change which may be noted in other parts of the Northern Hemisphere as well. Such a climatic trend is also indicated by the record of marine invertebrates, and by the character of certain sediments. This relatively continuous change in climate, as shown by reduced numbers of subtropical plants and increasing representation of the temperate element, constitutes a developmental trend and provides a basis for determining the date when a flora passed through a given latitude on its southward migration. The time-space concept supplies a critical tool in the recognition of floral sequence.

Importance of the time factor in land plant migration is obviously greater than in the case of mammals, individuals of which may travel wide distances in response to seasonal changes and food requirements. Rooted in the soil, with essentially fixed moisture supply and temperature during its lifetime, a tree may alter the range of its species only by the slow method of scattering seed into other favorable situations. Since the most critical stage in the life of a plant is the period of germination, it is apparent that major extensions in range may result only when a gradual change in climate has brought favorable growth conditions into bordering areas.

Modern habitats vary greatly in their topography and rainfall, and we may assume that there have been similar differences in environment in the past. It can scarcely be doubted that during the Tertiary, as today, vegetation was highly diversified over such limited areas as a single drainage basin. But there is much reason to believe that then, as now, trees

situated in and near sites of deposition were in the best position to contribute their leaves, fruits, and stems to the sediments which comprise the Tertiary. In other words, of all the varied floral units which may have occupied a region at a given time, only the forests of the lowlands, bordering streams, lakes, or lagoons, could regularly contribute to the record of that epoch. Occasionally mountain florules are found in association with the dominant flora of a formation, but they are always a minority element, and not infrequently show by their fragmentary preservation the effects of extensive transportation prior to burial. In view of the relative ease of their dissemination, pollen grains may commonly enter the deposits of lowlands from upland habitats. When genera not represented by heavier structures appear in the fossil record as pollen grains, the possibility arises that they lived upon adjacent slopes and ridges (Clements and Chaney, 1934). But in general, the dominant members of a fossil flora seem to have come from a single habitat, and are interpreted as representing the vegetation which occupied the borders of a lowland site of deposition.

The Tertiary flora which best illustrates a migration response to climatic change has as its dominant element the redwood (*Sequoia*) together with several of its modern associates, alder (*Alnus*), pepperwood (*Umbellularia*) and tan-oak (*Lithocarpus*). An associated element includes members of the modern deciduous hardwood forest of the eastern United States and eastern Asia, basswood (*Tilia*), beech (*Fagus*), chestnut (*Castanea*), elm (*Ulmus*), and hornbeam (*Carpinus*). A third element is made up of genera now restricted to Asia, such as katsura (*Cercidiphyllum*), maidenhair tree (*Ginkgo*), tree of heaven (*Ailanthus*), water chestnut (*Trapa*), and zelkoua (*Zelkova*). Such plants are typically temperate in their modern distribution. Their moisture requirements are high (40 to 60 inches annually), and the predominance of deciduous genera suggests summer as well as winter rainfall. This flora first appeared in the Eocene of high northern latitudes, including Alaska (Kenai flora), (Hollick, 1936) northern Siberia, Spitzbergen, and Greenland. Evidence that some of its genera ranged southward along mountain ranges during this epoch is to be seen in its occasional presence as a minor element in the subtropical floras which characterized middle latitudes in western America and western Europe during the Eocene (Chaney, 1938, p. 636; Reid and Chandler, 1933, p. 83). The existing forests of Alaska include a number of trees, such as the mountain hemlock (*Tsuga mertensiana*) and aspen (*Populus tremuloides*), whose modern distribution southward at sucessively higher altitudes in the Cordillera corresponds closely to that here suggested for the Eocene redwood forest. Except in the northern portions of their range, where they live at sea level, both of these trees occupy

habitats so remote from sites of deposition that their entrance into the contemporary record is rather unlikely. If a future change in climate should lower the temperature and precipitation in the western United States, the forests now living in our lowlands would give way to vegetation from the north and from the Cordillera. This northern and alpine vegetation would leave a record as soon as its altered range brought it down into the valleys, in close proximity to sites of deposition.

In like fashion the climatic trend of the Tertiary resulted in a nearly complete elimination of the subtropical flora from Oregon by the end of the Oligocene, and in the southward migration of the temperate forest which had previously been widespread across high northern latitudes. By early Miocene the redwood and many broad-leafed deciduous genera were dominating the forest of middle latitudes, both in western North America and in Eurasia. Although slightly modified during its migration from the north, this forest so closely resembled that of the Eocene in high latitudes that several European paleobotanists believed they were of the same age. Only the evidence of their stratigraphic occurrence has subsequently demonstrated that the "Arctic Miocene" flora of Heer comes from lower levels than the Bridge Creek and other Middle Tertiary floras from temperate latitudes. Continued climatic and topographic changes since the Miocene have further altered the composition and distribution of the Arctic-Tertiary flora. Complete elimination of *Sequoia* from Eurasia, and its present restriction in North America to western California, are an illustration of the mortality to be expected in so extended a journey through space and time. Many of the broad-leafed deciduous trees no longer live west of the Rockies, because of reduced precipitation during the summer. In the eastern portions of both the northern continents, where moderate climate is still characterized by summer rainfall, these broad-leafed deciduous genera of the Arctic-Tertiary flora have continued as the predominant element. Forests closely related to the Arctic-Tertiary flora, with other coniferous genera taking the place of *Sequoia*, have survived in the Cordillera as far south as Mexico and Guatemala. Temporary reversals there have been, as pointed out by Axelrod (1938) on the basis of his Pliocene studies; but from the Eocene to the Recent, this temperate forest has been shifted southward across 60 degrees of latitude as a result of the trend toward reduced precipitation and temperature.

At the time when the redwood forest covered the plains in arctic latitudes, the lowlands from Washington to California were occupied by vegetation of a subtropical type. Such older Tertiary floras as the Clarno, Comstock, Goshen, and Chalk Bluffs abound in genera with large thick leaves, such as avocado (*Persea*), chumico (*Tetracera*), fig (*Ficus*),

FIGURE 1. THE COAST REDWOOD (*Sequoia sempervirens*) forest at Mill Creek, Del Norte County, California, latitude 42° north.

FIGURE 2. LEAVES OF REDWOOD (*Sequoia langsdorfii*) from beds of older Tertiary on St. Lawrence Island, Alaska, at latitude 64° north.

REDWOOD FOREST AND LEAVES OF FOSSIL REDWOOD

FIGURE 1. THE VALLEY FOREST ON TATARE RIVER, PANAMA
At latitude 9° north. Forest contains many living equivalents of older Tertiary species.

FIGURE 2. LEAVES OF FIG
(*Ficus quisumbingi*) from beds of older Tertiary near Goshen, Oregon, at latitude 44° north (x ⅗).

SUBTROPICAL FOREST AND LEAVES OF FOSSIL FIG

Meliosma, palmetto (*Sabalites*) and siricote (*Cordia*). These genera are distributed in low latitudes at the present time, and are members of families which are largely or exclusively tropical. The trend toward colder and dryer climate has resulted in progressive restriction of these subtropical plants to the south. Some of them lingered on as late as the Miocene in favorable situations from the Oregon coast to southern California, but few survive today outside the tropics.

It is apparent that zonal climate has characterized western America throughout the Cenozoic. For when figs and palms lived in Oregon, redwoods and oaks ranged into Alaska. And when this northern forest was shifted into middle latitudes, plants with high temperature and moisture requirements were forced into low latitudes where they have survived down to the present. Similar evidence of zoning has been noted by Clark and Vokes (1936) for the marine invertebrates of the Tertiary. This concept of zonal distribution is at variance with the views of paleontologists who postulate cosmopolitan distribution of floras and faunas. Such distribution might be attributed to the redwood if its range during the Tertiary as a whole were considered, for it has been recorded from Ellesmere Island, in Arctic America, to Colorado, over a breadth of some 40 degrees of latitude. However at no one time is the redwood known to have been a dominant member of the forest across half this range of latitude, and any suggestion of its cosmopolitanism is therefore highly misleading. It may be predicted that when the details of distribution are more fully known for certain older floras and faunas of the continents, they also may be found to have been latitudinally restricted at any one epoch rather than wide-ranging. It may even be found that trilobites, brachiopods and other marine organisms were not so ubiquitous as has been assumed for any single epoch, and that correlations based upon them may come to be modified when we know more about the details of their occurrence in time and space. In any case it would be unwise to conclude from the present distribution of life and climatic zones that latitude has always been as critical a factor in climate control as it is today, for during times of major submergence there were doubtless increased facilities for circulation of air and ocean currents. It is also a well known fact that some living organisms have a wide range of tolerance and may occupy highly diverse climatic zones. However we can scarcely doubt that during the Cenozoic, and in preceding eras, there was a recognizable relationship between latitude and the distribution of most terrestrial plants.

Nearly three quarters of a century ago, in his discussion of homotaxis and synchronism, Huxley (1870) stated,

"It is possible that similar, or even identical, faunae and florae in two different localities may be of extremely different ages, if the term 'age' is used in its proper chronological sense. . . . those seemingly sudden appearances of new genera and species, which we ascribe to new creation, may be simple results of migration."

Applying the concept of homotaxis to the problems of Tertiary correlation, it seems clear that floral and faunal resemblances across a wide range of latitude may be an indication not of contemporaneity but of discrepancies in age. Correlation of Tertiary plant-bearing beds in western America is always subject to this application of the time-space concept. As our knowledge of the stratigraphic and geographic distribution of fossil floras increases, we shall be able to evaluate still more closely the time factor in plant migrations.

PHYSICAL GEOGRAPHY OF NORTH AMERICA DURING THE TERTIARY

The coastline and topography of the North American continent during the Tertiary may be reconstructed through a study of the composition and distribution of past vegetation. Forests of the coastal plains and lowland valleys have been recorded from Alaska to California, and upland plants are abundantly represented in continental deposits as far east as the Rocky Mountains and High Plains. Coastal floras are known from Texas to Virginia, with an outlier in Vermont which appears to represent an inland site. Not including minor oscillations which locally and temporarily modified the shores, there is evidence of two major differences in continental outline at the beginning of the Cenozoic. One of these, so fully described by Berry in his discussion of the Eocene floras of the southeastern United States, involved extension of the Mississippi Gulf northward to the southern tip of Illinois during the early Eocene, as judged by the occurrence of the typically coastal Midway and Wilcox floras. In the later Eocene this embayment was restricted southward to Arkansas (Berry, 1924). The most northerly records of Oligocene plants are from southeastern Texas to Mississippi (Matson and Berry, 1916a). Miocene formations in this area are largely marine and brackish water in origin, and the only flora recorded is from southern Mississippi and northern Florida (Berry, 1916a). The record of Pliocene plants is confined to southernmost Alabama (Matson and Berry, 1916b), although the Citronelle formation in which they occur extends from southern Louisiana to Florida. The progressive withdrawal of the Mississippi embayment to its present shores during the Cenozoic has also been described by Russell and Russell (1939) in connection with their study of the Mississippi delta. At its stage of maximum extension in the Lower Eocene, this shallow sea profoundly modified the climate in the interior of North America (Berry, 1930b, p. 33-40) and even as late as the

Pliocene its influence on the vegetation in Oklahoma has been noted (Chaney and Elias, 1936, p. 27).

The other marked difference in the Eocene coastline involved a broad land connection between North America and Asia across Bering Strait. This is known from the occurrence of the typical Arctic-Tertiary flora on St. Lawrence Island, a flora recorded both from Siberia and Alaska. It includes the critical genus *Sequoia*, whose living coastal species is unable to migrate even for short distances from the mainland to adjacent islands (Chaney, 1930). Evidence that this land connection was maintained until the late Tertiary is afforded by numerous other elements common to the fossil floras of both continents. Supplementary data are afforded by Tertiary mammals; Matthew (1939) states that

"The North Pacific basin was closed to the northward by the Alaskan land bridge during a large part if not all of the Tertiary," . . .

In an earlier paper, he considered the probability that North America and Asia were separated during the Middle and Upper Eocene, a condition which would be consistent with relative submergence in other northern continents at this time (Matthew, 1906). Subsequent discovery of Eocene mammals with American affinities in Mongolia has led Granger (personal communication, December 11, 1939) and others to question the existence of more than a transient Bering seaway during the Eocene. There is no record of marine encroachment on the western shores of the Seward Peninsula until the close of the Tertiary (Smith, 1939), and the existence of a broad land connection during most of the period seems well established.

Withdrawal of the sea which extended inland to eastern Oregon during the Cretaceous (Packard, 1929) brought the shores of the Pacific to essentially their present position at the beginning of the Cenozoic. Several narrow encroachments of Tertiary seas landward into Washington and Oregon have been recorded by Weaver (1937) on the basis of invertebrate fossils. Similar evidence has enabled Clark (1921) to map somewhat more extensive embayments in California. The presence of coastal types of vegetation at inland situations during the Eocene and Miocene is consistent with such embayments, and it has been suggested that broad valleys extending landward provided interior habitats which were favorable to the persistence of warm temperate plants as late as the Miocene (Chaney, 1938). The present-day extension of the bald cypress from the Gulf of Mexico up the Mississippi Valley into Illinois is a similar example of the topographic control of plant distribution.

Relief has always been a critical factor in the development and distribution of vegetation. Marked differences in exposure and in climate between uplands and lowlands may be assumed to have differentiated Tertiary forests in regions with diversified topography, although as above

noted only the lowland forests were regularly preserved in the fossil record. Equally important in climatic control are the effects of mountains upon areas to the leeward. No one can cross the Cascade Range without observing the change from humid forests on their western slopes to desert scrub at the east. Differences of the same order may be noted in the Cascade region as far back as the Pliocene; the redwood is recorded at a locality of this age in western Oregon, and is absent from Pliocene floras on the eastern side of the range. In the Miocene, however, redwoods ranged from western Oregon across the area now occupied by the Cascades into eastern Oregon and Idaho, although by the end of the epoch their numbers were greatly reduced. We may conclude that this topographic and climatic barrier, which today so profoundly differentiates the eastern part of Oregon from the western, was not in existence during the early Miocene; it had its inception toward the close of the epoch, with further uplift during the Pliocene.

Of further value in establishing the continuity of coastal forests across the present axis of the Cascades is the subtropical assemblage recorded from beds of the Eocene. The Comstock flora of west-central Oregon, as studied by Sanborn (1935), has a composition similar to that of the Clarno flora from the John Day Basin. Similar resemblances have been noted between Eocene floras on opposite sides of the Cascade Range in Washington. We may conclude that lowlands extended eastward across Washington and Oregon until nearly the end of the Miocene, after which time the existence of the Cascade barrier is indicated by differences in vegetation from west to east. Such dating is in agreement with evidence of a strictly geological nature regarding the age of this mountain range (Chaney, 1932). There appear to have been numerous volcanoes along the present axis of the Cascades during the early Tertiary, and their numbers were increasing by the middle of the period. But no effective north-south barrier rose to isolate the Columbia Plateau and the northern Great Basin from the tempering effects of the Pacific Ocean until the end of the Miocene, when the vegetation to the east shows the effects of increasing continentality.

The distribution of Tertiary floras in the regions now occupied by the Sierra Nevada and Coast Ranges likewise provides a basis for concluding that these California mountains were lower during most of the period than they are today. Bordering the shores, which extended across the present Sacramento Valley in the Eocene, were forests whose leaves and fruits have accumulated in shaly members of the older Auriferous Gravels. First described by Lesquereux (1878) as Pliocene, the subtropical Chalk Bluffs flora was shown by MacGinitie (1938) to be Middle Eocene and to represent the same climatic province as Eocene floras

nearer the present coast. The intervening Coast Ranges of today were therefore not in existence at this time, nor is there evidence of their climatic effects before the close of the Miocene. Comparison of the Upper Miocene San Pablo flora of the San Francisco Bay area (Condit, 1938) with newly discovered material of essentially the same age in the interior has recently been made by Condit (personal communication, November 1939), who concludes that no intervening barrier existed at this time. The first evidence of continentality in the vegetation of the western slopes of the Sierra Nevada is found in the Table Mountain flora, whose age is placed as transitional between the Miocene and Pliocene (Condit, personal communication, November 1939). The rising of the Coast Ranges during the later Tertiary is further indicated by the increasingly arid aspect of Pliocene vegetation studied by Dorf (1933) and Axelrod (1937).

All available evidence, including the coarse texture of the Auriferous Gravels, suggests that the Sierra Nevada were in existence during most of the Tertiary. However, they must have been low enough locally to admit mild moist winds from the Pacific into the present Great Basin Province. Relationship of the Chalk Bluffs flora to the Wind River, Green River, and older Yellowstone floras (MacGinitie, personal communication, December 1939) indicates the extension of oceanic climate into the western and central Rockies during the Eocene. The Oligo-Miocene forest from Elko, Nevada, contains the coastal elements which characterize Miocene vegetation in western California. The Cedarville flora is considered by LaMotte to indicate the absence of highlands between northwestern Nevada and the ocean in the late Miocene; at present the Warner Mountains, the Klamath Mountains, and the Coast Ranges lie to the west of the principal locality at 49-Camp, Nevada, where modern temperature and precipitation are wholly unsuited, both in amount and seasonal distribution, to support the redwood, hickory and beech which lived there in the later Miocene (La Motte, 1936).

Toward their southern end, there is evidence that the Sierra Nevada were being uplifted as early as the Miocene epoch. The continental character of the Tehachapi flora of southern California has been pointed out by Axelrod (1939, p. 35, 37) who considers that a mountain range rising on the west was affecting this vegetation in the Middle Miocene. Continued orogeny has subsequently isolated still further the Mohave area from the sea, as indicated by comparison of Pliocene and Recent climate with that of Tehachapi time (Axelrod, 1939, p. 81). The present diversity of vegetation in western America is in striking contrast to its uniformity which, until near the end of the Miocene, extended from the coast across the Columbia Plateau and the Great Basin. This diversity appears to be directly correlated with the diastrophic events of the later

Tertiary, during which our existing mountain ranges were uplifted and our present topographic control was established.

Unlike the Cascades and Sierras, the Rocky Mountains constituted a topographic barrier throughout the Cenozoic. This is indicated by marked differences in composition between Eocene and later floras in the Rocky Mountain province and those farther west. Living under a continental type of climate, the vegetation of the Fort Union included many more temperate genera than the contemporary forests bordering the Pacific. Recent studies by Love (1939) suggest that the Laramide Revolution continued into the Oligocene, and perhaps even into the Pliocene, in the Absaroka Range of Wyoming. As a result of such sustained orogeny during part or all of the Tertiary, the forests of the northern High Plains were largely displaced by grasslands during succeeding epochs. The fossil record indicates only the scattered presence of hackberries (Chaney, 1925) and sycamores (Chaney and Elias, 1936, p. 10) along stream courses during the middle and later Tertiary. The occurrence of grasses over wide areas has been demonstrated by Elias (1935). In Oklahoma and Texas, a more humid type of vegetation is recorded during the Pliocene, due perhaps to the lower altitude of the Cordillera southward, or to the influence of the still enlarged Mississippi embayment (Chaney and Elias, 1936, p. 27).

Farther east the floral record of the Tertiary is largely confined to the Atlantic and Gulf Coastal Plains. Eocene floras are well developed in the Mississippi embayment, and a record of related but little known fossils in Vermont suggests a northward extension of the Eocene forest (Berry, 1937b). Oligocene vegetation is represented over a restricted area in southern Texas, Louisiana and Mississippi. The only record of Miocene plants is in Florida and Mississippi, and northward in Virginia and the District of Columbia (Berry, 1916b). Pliocene floras are limited to the area bordering the present Gulf coast.

Since active vulcanism was not mantling the uplands here to produce conditions favoring plant preservation, only indirect evidence is available regarding the character of upland vegetation. The floras which occupied eastern America during the Cretaceous provide the most reliable data. Berry (1930b, 12-14) has discussed the elimination of many Cretaceous genera from the southern coastal plain before the Lower Eocene. Many of them are typically temperate in their modern distribution, including *Acer, Fagus, Pinus, Populus, Salix* and *Sequoia*. Berry believes they were driven from the embayment region by the change toward subtropical climate at the beginning of the Eocene. The restriction of the inland Cretaceous sea may well have eliminated *Sequoia* from eastern America at this time, but other members of the temperate forest may be supposed

to have moved northward to the regions where they are still found. All of these genera are common members of the upland Tertiary forests in western America, where extrusive vulcanism provided sediments and conditions suitable for their preservation in the fossil record. From a study of modern vegetation in eastern America, Fernald (1931) has suggested that many existing genera occupied this region as far back as the Cretaceous. Such a reconstruction of the upland vegetation in eastern America is purely tentative, but is consistent with all of the evidence now available.

THE BEARING OF TERTIARY PLANT DISTRIBUTION ON THE PERMANENCE OF CONTINENTAL PLATFORMS AND OCEAN BASINS

This effort to reconstruct the character and distribution of Tertiary vegetation has been made for the purpose of drawing the continental outlines and restoring the topography of North America during the period preceding our own. Taken in conjunction with data on similar floras in Eurasia, it has the further value of indicating the general position of continents and ocean basins in the Northern Hemisphere as far back as the Eocene.

Since we are living in a day when climatologists slide continents around and about the surface of our sphere, when certain geophysicists manipulate, almost with abandon, the position of its poles in relation to continental masses, we may profitably consider the evidence of continental stability afforded by Tertiary plants. Such evidence seems particularly well suited to establish the nature of land and water relations during the past, not only because plants are relatively sensitive indicators of climate, but because their Tertiary distribution is so generally used by the exponents of continental drift in support of this hypothesis.

Discussing the flora of the London Clays, Reid and Chandler (1933, p. 71) have brought together critical evidence sustaining the assumption that the poles occupied their present position during the Eocene. On several occasions Berry (1922; 1930b, p. 29) has emphasized the circumpolar occurrence of Eocene floras, and has mapped their distribution; in addition he has discussed their occurrence in zones corresponding to those of today (Berry, 1930a). The map on Figure 1 is designed to show the existence of latitudinal zoning in the northern continents during the early Tertiary. Subtropical, temperate, and cool-temperate zones may be differentiated on the basis of the fossil floras whose occurrences are here plotted. The contrast between the vegetation of the subtropical and temperate zones is shown by fossil leaves from Oregon and Alaska, as figured on Plates 1 and 2, and by the aspect of the modern forests in Panama and California, which contain living equivalents of these Eocene

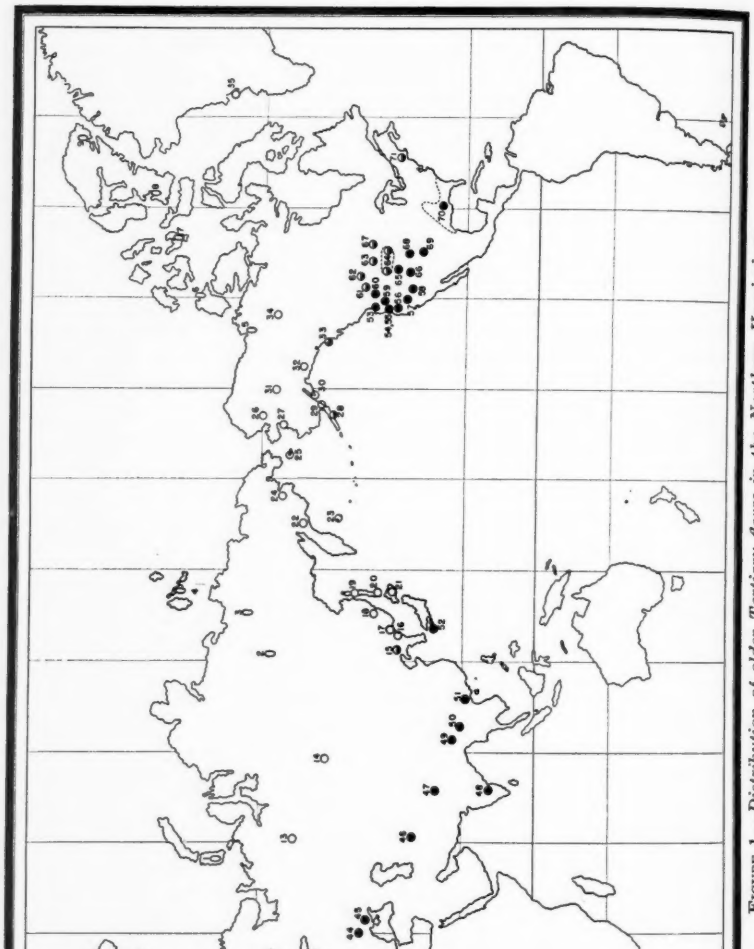

FIGURE 1.—*Distribution of older Tertiary floras in the Northern Hemisphere*

LIST OF EOCENE* LOCALITIES OR FORMATIONS

SHOWN ON FIGURE 1

Cool temperate

1. Novaya Zemlya
2. Tschirmyi, Siberia
3. Tas-takh Lake, Siberia
4. New Siberia Islands
5. Mouth of Mackenzie River, Canada
6. Banks Island
7. Bathurst Island
8. Ellesmere Island
9. Grinnell Land

Temperate

10. Iceland
11. Sabine Island, Greenland
12. Spitzbergen
13. Lozva River, Siberia
14. Simonova, Siberia
15. Fushun, Manchuria*
16. Kisshu-Meisen & Ryudu, Korea
17. Possiet Bay, Siberia
18. Sikhota-Alin Mts., Siberia*
19. Dui, Sakhalin
20. Naibuchi, Sakhalin
21. Shitakara and Ishikari, Hokkaido, Japan
22. Korf Gulf, Siberia*
23. Commander Islands*
24. Anadyr River, Siberia
25. St. Lawrence Island
26. Kobuk River, Alaska
27. Norton Sound, Alaska
28. Chignik, Alaska
29. Cape Douglas, Alaska
30. Port Graham, Alaska
31. Central Yukon Valley, Alaska
32. Berg Lake, Alaska
33. Kupreanof Island, Alaska
34. Great Bear River, MacKenzie
35. Atanekerdluk, Disko Island, Greenland

Subtropical

36. Antrim County, Ireland
37. Isle of Mull, Scotland
38. London Clay, England
39. Paris Basin, France
40. Celas, France*
41. Sezanne, France
42. Bavarian Alps*
43. Jesuitengraben, Bohemia*
44. Kiev, Ukraine
45. Elisabethgrad, Ukraine
46. Er-oilan-duz, Turkestan*
47. Kasauli, India
48. Deccan Plateau, India
49. Assam, India
50. Burma, Further India
51. Na-giao, Indo-China*
52. Takashima, Kyushu, Japan
53. Steel's Crossing, Washington
54. Comstock, Oregon
55. Goshen, Oregon
56. Ashland, Oregon
57. Weaverville, California*
58. Chalk Bluffs, California
59. Clarno, John Day Basin, Oregon
60. Swauk, Washington
61. Calgary, Alberta
62. Red Deer River, Alberta
63. Upper Ravenscrag, Saskatchewan
64. Fort Union, from Yellowstone Park to South Dakota
65. Wind River, Wyoming
66. Green River, Wyoming
67. Roche Percee, Saskatchewan
68. Denver beds, Colorado
69. Raton, Colorado and New Mexico
70. Wilcox, Claiborne and Jackson, Southeastern United States
71. Brandon, Vermont

* Localities with an asterisk (*) are Oligocene.

FIGURE 1.—*Distribution of older Tertiary floras in the Northern Hemisphere*

trees. In the later Tertiary, the temperate zone was shifted southward into middle latitudes, and the subtropical zone into low latitudes. These zones, as indicated by Tertiary plants, were in essentially the same latitudes, in both North America and Eurasia. Zones occupied by cor-

responding floral units of today have a similar relationship to latitude around the Northern Hemisphere. If the north pole had been situated where Köppen and Wegener (1924) would place it during the Eocene, at latitude 45 degrees north and longitude 160 degrees west (in the Pacific ocean about 2000 miles west of Oregon and nearly 1500 miles south of Alaska), the island of Spitzbergen would have lain at latitude 40 degrees north, its temperate vegetation wholly consistent with modern climate at this distance from the pole. But such a shift places the Kenai flora of Alaska, of essentially the same age and composition, at latitude 75 on the Wegener map—almost 10 degrees nearer the north pole than the northernmost fossil locality on the basis of the existing polar position. Every other American Tertiary flora lies farther out of climatic alignment on the Wegenerian map than it does under existing polar relations. It is amusing to note, and significant as indicating a provincial partiality, that in taking care of their own Tertiary forests, certain Europeans have condemned ours to freezing. Berry (1937a) must have been thinking of such absurdities when he wrote regarding the Wegenerian hypothesis that it "raises more distributional problems than it solves."

Returning to a projection based upon existing earth conditions, Figure 2 shows that in both North America and Eurasia, older Tertiary floral units ranged somewhat farther north on the windward than on the leeward coasts. Lines connecting similar fossil floras, which are considered to represent essentially similar climatic conditions, are here termed *isoflors*. It is believed that their general correspondence in position to Eocene isotherms is indicated. Modern vegetation (Rübel, 1930) shows a similar trend northwest-southeastward across the northern continents, and roughly parallel to existing isotherms (Hann, 1887) as indicated on Figure 3. Present departures of isotherms from coincidence with parallels of latitude are interpreted as resulting from the tempering effects of ocean currents on the western sides of continents in middle and high latitudes, and from increasing continentality toward the east. It seems entirely reasonable to assume that similar distribution of vegetation and temperature during the Eocene resulted from the same controlling factors, and to conclude that land and sea relations, as well as planetary circulation, were essentially like those of today.[1]

Following the continental pattern suggested by Wegener for the Eocene, there is no basis for explaining the sharp upturning of the isoflors off the coasts of England and Scandinavia, for no Eocene equivalent of the Gulf Stream could have washed these shores when they were in the midst of his Pangæa. It is a question whether an Eocene Japan Current could

[1] Brooks (1928, fig. 14, p. 154) shows a map of part of Europe, after F. von Kerner, with a similar trend of Tertiary isotherms, based on wholly different evidence.

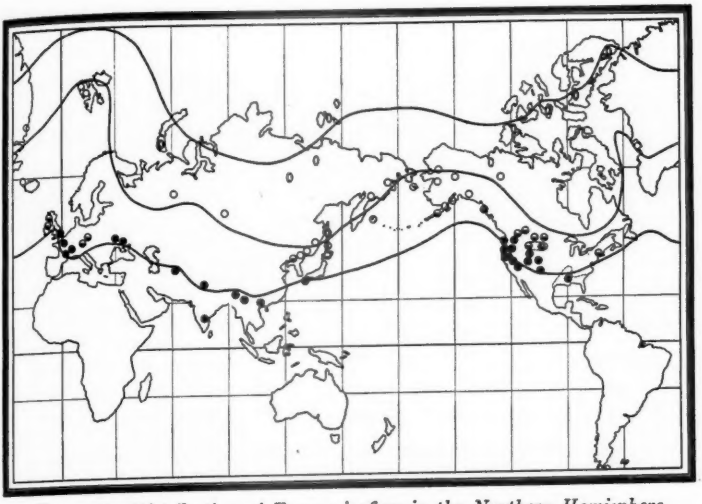

FIGURE 2.—*Distribution of Eocene isoflors in the Northern Hemisphere*
(For legend see Figure 1.)

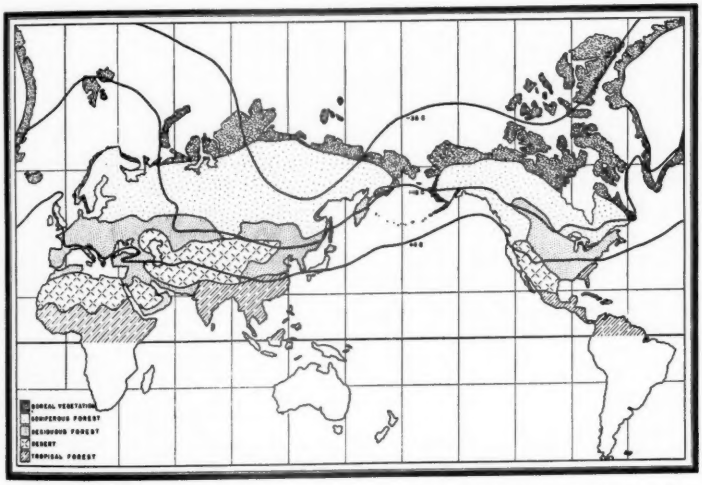

FIGURE 3.—*Distribution of January isotherms and modern vegetation in the Northern Hemisphere*

have maintained itself across the enlarged Pacific basin pictured by Wegener, and have influenced the distribution of climate and vegetation on the Pacific coast of North America as it does today, and as it did

during the Tertiary if the position of the isoflors has the significance we assign to it.

We may therefore conclude that the distribution of ocean basins and continental platforms has been essentially unchanged since the Eocene. There is no acceptable evidence of northward drift unless Eurasia as well as North America has moved poleward; westward drift of North America from Europe seems impossible to explain in view of isofloral distribution during the Eocene. The hypothesis that continents drifted to their present positions as late as the Pleistocene, far from finding support from Tertiary floras, must meet the evidence that forest distribution has been controlled by existing land and sea relations throughout the Cenozoic.

Discussion of the causes of Tertiary changes in climate is not within the scope of this paper. The effects of continental uplift, involving altered circulation of air and water, have already been mentioned; these are fully considered by Brooks (1928) in his significant volume "Climate Through the Ages," and have been developed in the discussions of Eocene floras by Berry (1930b, p. 33-40) and by Reid and Chandler (1933, p. 70-82). The possibility that changes in solar radiation may also be involved in Eocene climate is considered by the latter authors (Reid and Chandler, 1933, p. 70-74). My own opinion is that the factors of physiographic change and of varying solar radiation are together competent to cause the changes in climate which are indicated by Tertiary migrations. However, the problems of climate and its relation to vegetation are so complex that we must admit that there may be other factors, not yet considered, which may have affected forest environments during the past.

CONCLUSION

Throughout the Tertiary, North America has been a rising continent as judged by the record of its vegetation. Narrow bordering seas have largely withdrawn, mountain ranges have been uplifted, until we of the Recent epoch have inherited great diversity of environment. Controlled largely by these earth changes, the climate has tended toward lowered temperature and rainfall. Resulting forest migrations across the continents enable us to determine the sequence and age of plant-bearing deposits. The pattern of land vegetation around the Northern Hemisphere indicates that the factors controlling air and water circulation have been essentially the same since the Eocene—that North America and Eurasia have stood in their present positions since the dawn of the Cenozoic. Evidence of land plants of earlier times, less completely known and interpreted, seems also to refute the hypothesis of continental drift. Forests under compulsion of climatic change, rather than the con-

tinents on which they live, appear to have been the wanderers during the history of life upon the earth.

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UNIVERSITY OF CALIFORNIA, BERKELEY, CALIFORNIA
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